THE WELLMAN-SEAVER-MORGAN CO.

CLEVELAND, OHIO, U.S.A.

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Hydraulic Turbines

By Courtesy of Canadian National Railways

GENERAL OFFICES: CLEVELAND, OHIO
WORKS: CLEVELAND AND AKRON

District Offices

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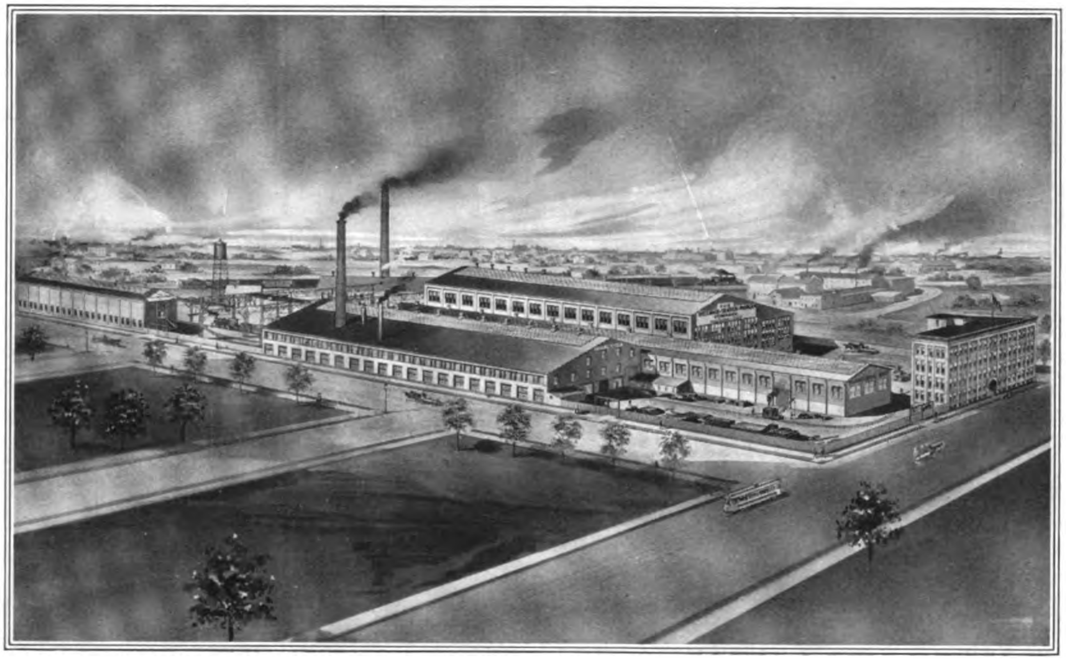
INTRODUCTION

THE development of the hydraulic turbine in the United States during the last fifteen years has been phenomenal. Prior to this period, American builders were unquestionably outranked by those in Europe. The hydraulic turbine, although built for many years in America, had been developed experimentally with little recourse to theory. European designers, on the contrary, had analyzed the theory of the turbine with great care, and, although somewhat lax in their experimental work, had acquired a decidedly superior knowledge of the art.

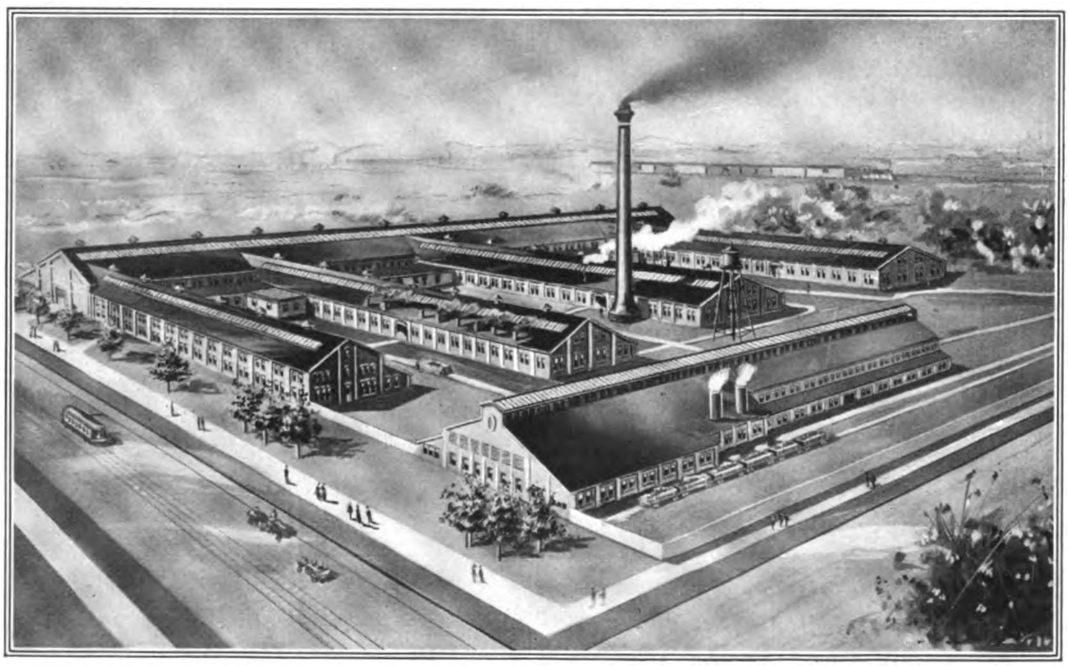
About the year 1905, however, the development of water power on a large scale in this country stimulated American turbine builders to a more progressive policy. Since that time the improvement in turbine design has been most remarkable, until today the turbine builders of the United States lead the world. No other continent has developed its water power on so large a scale as North America, and the turbines for these mammoth plants are of a size and refinement of design unparalleled in Europe or elsewhere.

In this development The Wellman-Seaver-Morgan Company has taken a conspicuous part. Some of the installations illustrated in the following pages and following bulletins are the largest of their respective kinds in existence. This company has spared no expense in developing its facilities for handling the turbine business, both as to construction and design. Much special shop equipment has been installed, and particular attention has been paid to the organization of a competent engineering department. The designers in this department are specialists, and their work is supplemented by a continuous series of experimental tests. These tests are made at Holyoke, Mass., which at present is the only official testing flume in the United States, and they have been a very important factor in the development of the American turbine to its present state of high efficiency. In this respect The Wellman-Seaver-Morgan Company has been a leader. This company was first to obtain an efficiency of 90% at Holyoke (Test No. 1799, efficiency 90.47%), likewise was first to obtain an efficiency of 92% (Test No. 2497). Since that time runners have been developed to meet practically all ordinary conditions at an efficiency of 90% or over when tested in the Holyoke Flume. Under favorable conditions and with vertical settings, results in the field show efficiencies as high as 93%.

All installations are specially designed to suit the conditions under which they are to operate. We are prepared to furnish complete hydraulic turbine equipment including governors, relief valves, pressure regulators, penstock valves and other accessories. The facilities of our engineering department are at the service of our customers at all times.

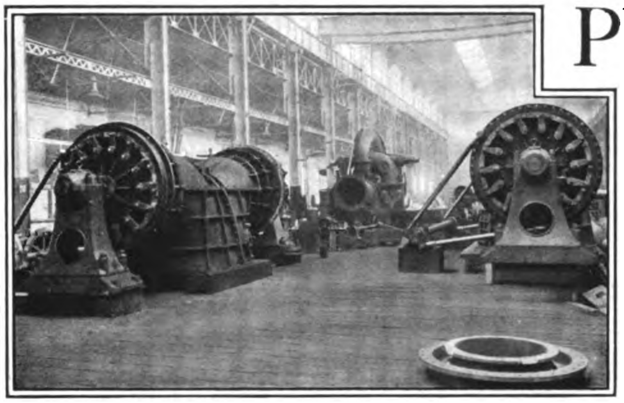


CLEVELAND WORKS



AKRON WORKS

TURBINE CHARACTERISTICS



ERECTING FLOOR—AKRON WORKS

PURCHASERS of hydraulic turbines, engineers or laymen, have no occasion to study the theory of hydraulic design. They are concerned chiefly with a study of the mechanical design, in its relation to the successful operation of the plant, and an analysis of the hydraulic characteristics of the turbine proposed. The character of the power and efficiency curves is usually of vital importance, if the best results are to be obtained.

HOLYOKE TESTS

To the experienced engineer, mechanical design speaks largely for itself, but the hydraulic characteristics can be judged only by data of past performances of similar nature. Hence, it has become standard practice among purchasers of turbines, to require tests to be submitted, showing the results obtained by the manufacturer with a turbine of similar characteristics. Holyoke tests are usually used for this purpose, and it is not expected that the test wheel should be of the same size as that for the proposed installation, or that the head should be the same. The only essential point is that the two wheels shall be of the same type, or technically speaking, shall have the same specific speed. Experience has shown that results under different heads and with different sizes of runners can be accurately deduced from the Holyoke tests of small size models.

SPECIFIC SPEED

"Specific speed" is a term used to designate the type of a turbine runner or wheel. It is the speed at which the wheel would run if it were so reduced in size, without changing the design, as to develop 1 HP under 1 ft. head. In Europe the units are 1 metric horsepower and 1 meter head.

Specific speed is a complete measure of the possible performance of a runner under any head, both as to power and speed. It is not a measure of its efficiency but aside from that consideration it is an absolute type characteristic, and, given the specific speed of a runner, it is possible

KEOKUK RUNNER LOADED FOR SHIPMENT

RUNNER FOR 10 800 HP TURBINES
CEDARS RAPIDS MFG. & POWER CO.

SPECIFIC SPEED

to decide at once whether it is suitable for a given set of conditions.

Let P = Horsepower.
N = Rev. per min.
H = Head
N_s = Specific Speed

Then $N_s = \frac{N\sqrt{P}}{H^{5/4}}$

The Power (P) usually considered in figuring N_s is the maximum Horsepower which the wheel can deliver at a reasonably good efficiency, say 80%, or more. For example, if a test runner shows 150 HP at 300 RPM under 18 ft. head, its specific speed is

$$N_s = \frac{300\sqrt{150}}{18^{5/4}} = 99$$

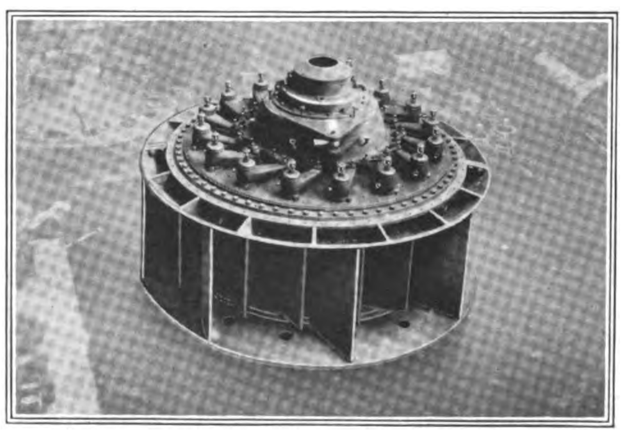
Also, if it is desired to select a runner for an installation requiring units with a capacity of 12 000 HP each, under 30 ft. head, at 63.5 RPM,

$$N_s = \frac{63.5\sqrt{12000}}{30^{5/4}} = 99$$

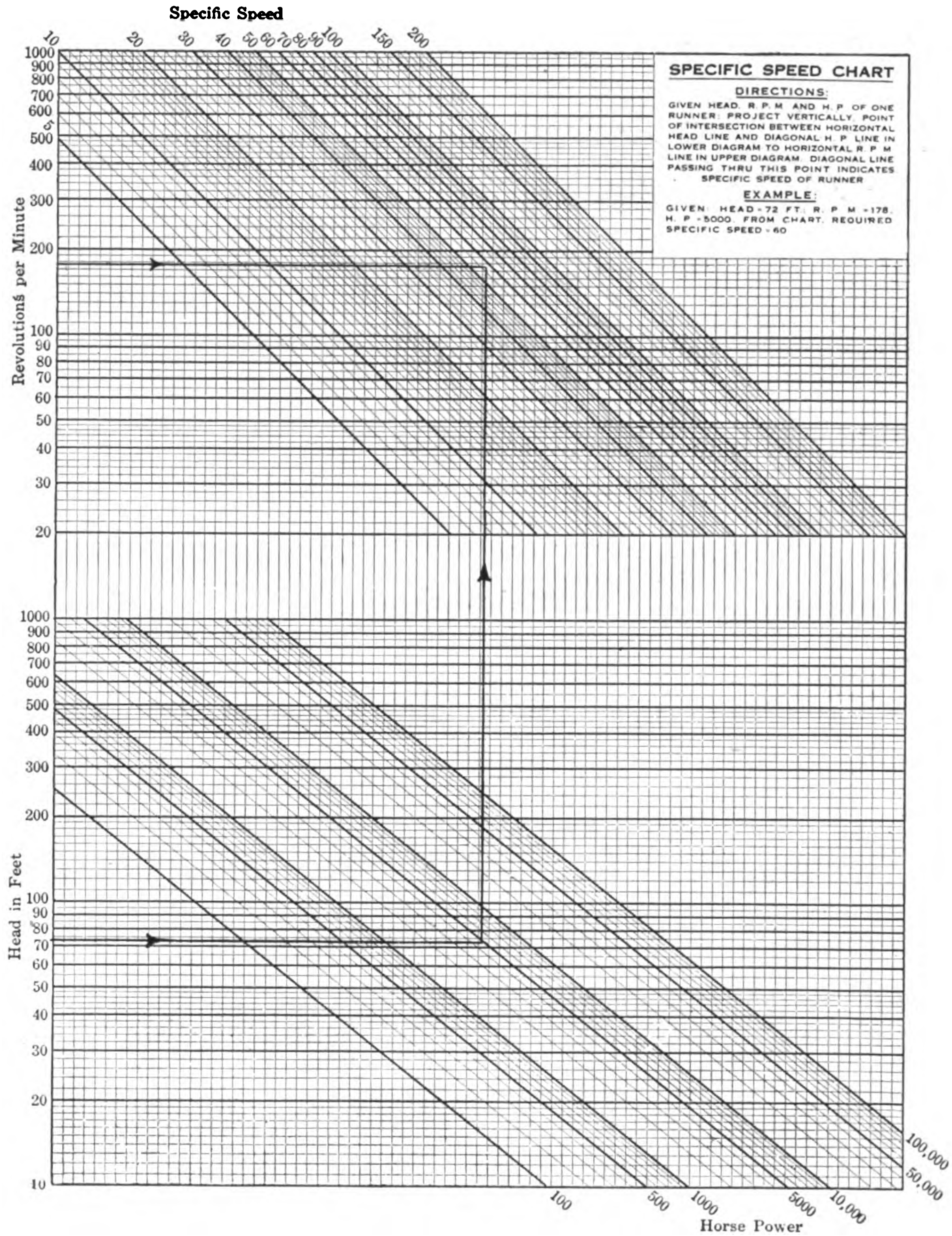
The specific speed is the same, and therefore it follows that the test wheel is suitable for this installation, provided its characteristics of efficiency are satisfactory.

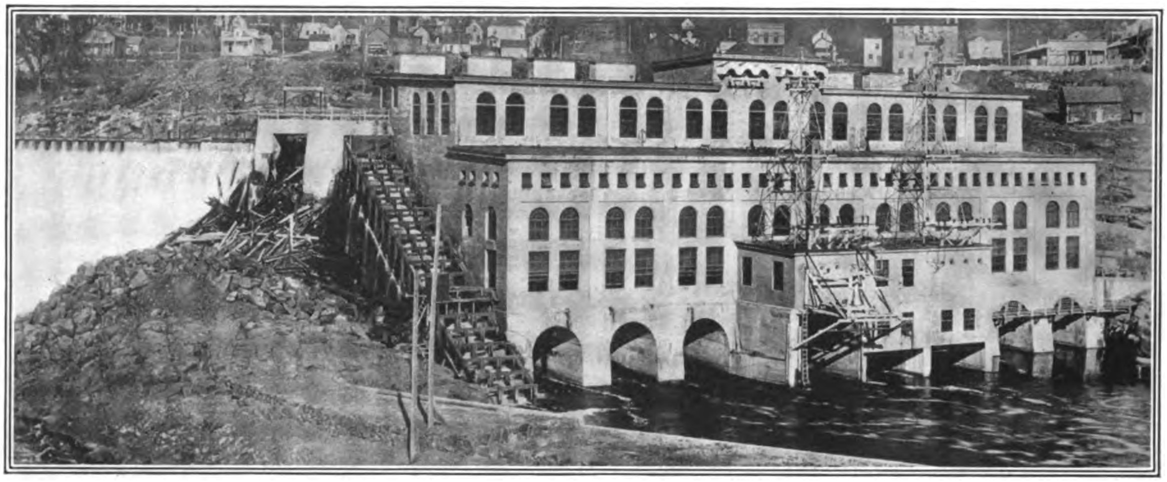
It should be noted that specific speed is always based on the capacity of a single runner. If a unit has two or more runners, N_s should be calculated from the power of one runner and not the total power of the unit.

The diagram on page 7 supplies a convenient graphic method of deducing the specific speed of a runner from any given set of conditions without the use of the above formula.



ONE OF THE THREE 4250 HP VERTICAL CONCRETE SPIRAL CASING TURBINES FURNISHED THE CENTRAL MAINE POWER CO.


Specific Speed
10
20
30
40
50
60
70
80
90
100
150
200
Revolutions per Minute
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
SPECIFIC SPEED CHART
DIRECTIONS:
GIVEN HEAD. R. P. M. AND H. P. OF ONE RUNNER: PROJECT VERTICALLY. POINT OF INTERSECTION BETWEEN HORIZONTAL HEAD LINE AND DIAGONAL H. P. LINE IN LOWER DIAGRAM TO HORIZONTAL R. P. M. LINE IN UPPER DIAGRAM. DIAGONAL LINE PASSING THRU THIS POINT INDICATES SPECIFIC SPEED OF RUNNER
EXAMPLE:
GIVEN: HEAD - 72 FT.; R. P. M. - 178. H. P. - 5000. FROM CHART. REQUIRED SPECIFIC SPEED - 60
Head in Feet
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
100
500
1000
5000
10,000
50,000
100,000
Horse Power



PLANT OF THE MINNEAPOLIS GENERAL ELECTRIC CO. AT TAYLORS FALLS, MINN., EQUIPPED WITH TWO 4 200 HP W-S-M TURBINES

EFFICIENCY

The efficiency of hydraulic turbines, in common with other prime movers, is constantly receiving more consideration. Practically all water powers are ultimately developed to the limit of water available. Higher efficiency of the turbines means more power, and hence more income from the same investment. A difference in turbine efficiency of 5% may frequently mean the difference between an investment paying normal dividends and one paying nothing. It is not unusual, therefore, for the purchaser to offer a bonus for additional efficiency. This acts as an incentive to the manufacturer to perform extra experimental or investigative work in the effort to secure unusually high results.

Considered by itself, it is manifest that high efficiency is always desirable. It often happens, however, that efficiency must be subordinated more or less to other considerations. For example, it may be desirable to use a wheel of lower efficiency in order to secure higher speed, or more power at a given speed, than would be possible with a more efficient wheel. Or, it may be necessary to sacrifice low-load efficiency in order to improve high-load efficiency, or vice versa.

The problem of suiting the efficiency characteristics of the turbine to the operating conditions of the plant often becomes very complicated, and can seldom be solved satisfactorily except in conference with the manufacturers. The question of what results can be obtained depends largely upon what results have been already developed, and the manufacturer is the only one in full possession of the latter information.

However, as a matter of general information and for use in preliminary studies which need not be strictly accurate, published results of tests are of considerable value to engineers engaged in water power development. They form a practical basis for approximate calculations, and as such are very useful. It is for this purpose that the following tests are published.

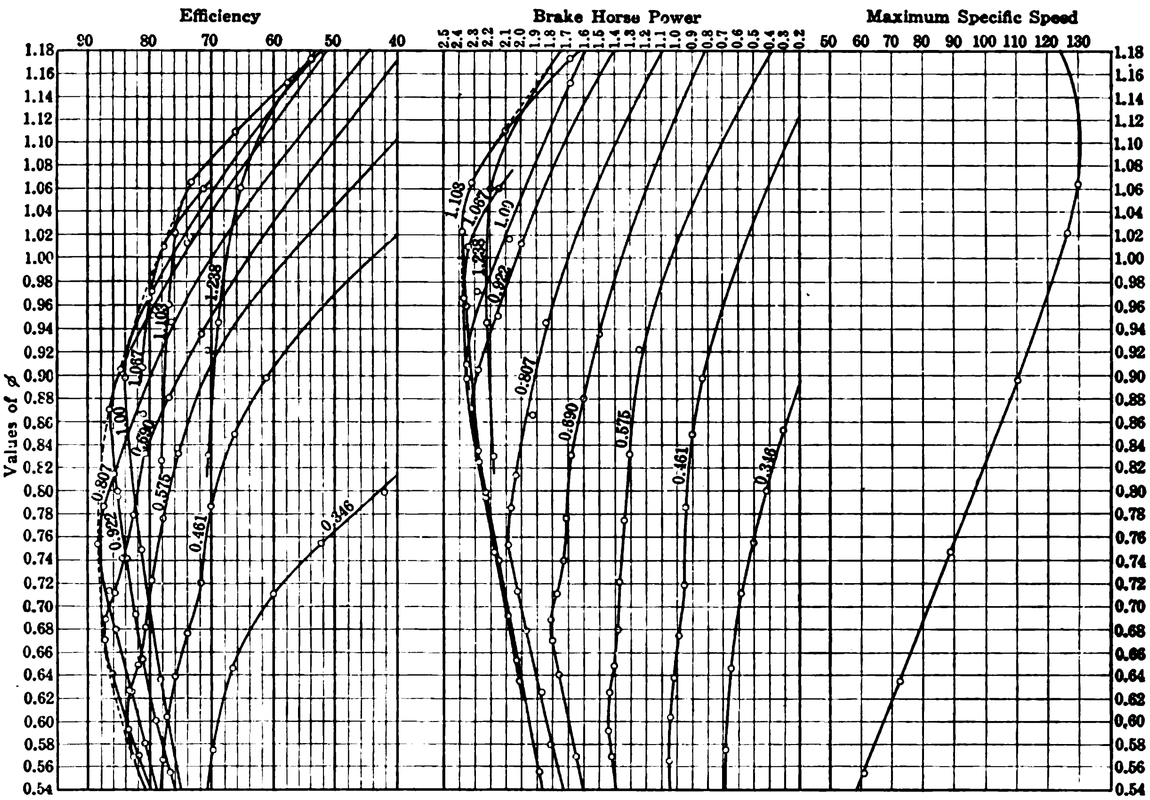


FIG. 1.—HOLYOKE TEST OF 23" EXPERIMENTAL RUNNER A—N_s=93

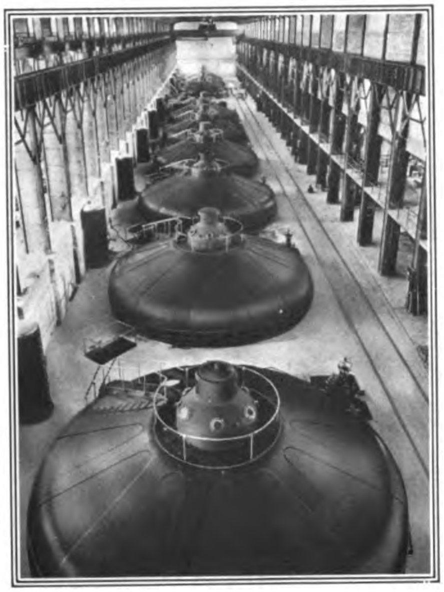
TEST DATA

This is a test of a high speed runner, the term "high speed" being used in the sense of high specific speed. In the design of this runner, peak efficiency has been sacrificed somewhat in favor of other characteristics. The curves are plotted directly from the Holyoke test, speed and power being reduced to a basis of 1 ft. head, according to the principle that, for constant efficiency, the speed varies as the $\sqrt{H}$ and the power as $H^{\frac{3}{2}}$. These curves show the HP and efficiency of the wheel plotted to speed. Speed, however, is expressed, not in RPM, but in terms of ϕ, ϕ being the ratio between the peripheral speed of the runner (based on its "rated" diameter) and the spouting velocity of the water due to the head.

$$\phi = \frac{N \times \pi D}{60 \times \sqrt{2gH} \times 12},$$

D being the rated diameter of the runner in inches.

Another curve is shown, giving the maximum specific speed of the runner for each value of ϕ. The specific speeds are calculated from the power shown by a dotted curve



100 000 HP PLANT OF THE CEDARS RAPIDS MFG. & POWER CO.

forming an envelope of the HP curves. This curve represents the maximum power obtainable for each speed, and is the result which would be obtained if an infinite number of gate openings had been run, up to the limit of full gate opening.

TEST DATA

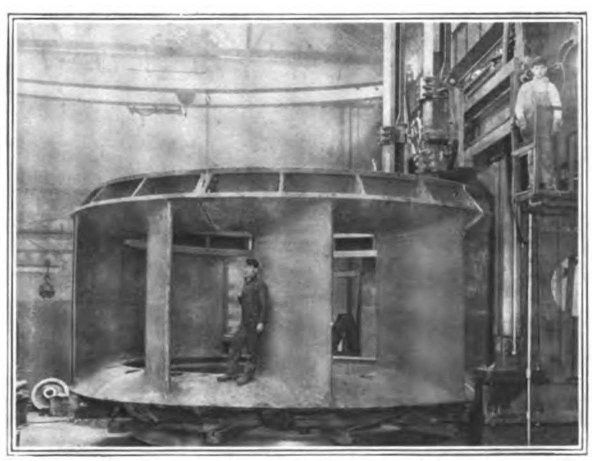
It will be observed that the maximum efficiency of this wheel occurs at a speed of about $\phi = 0.780$. This value is taken from the dotted line which forms an envelope of the efficiency curves, for the reason that the actual gate openings used in the test do not appear to show the maximum efficiency of the wheel. This value, $\phi = 0.780$, should therefore be regarded as the "normal" speed of the wheel. It is simply the speed which produces maximum efficiency. It does not necessarily follow, however, that this wheel will always be selected to run at that exact speed under normal plant conditions. Some other speed may be selected, for special reasons, and it should be observed that any speed between $\phi = 0.640$ and 0.874 may be selected without sacrificing more than 2% peak efficiency. Other considerations aside, however, the normal speed of this runner is $\phi = 0.780$.

Suppose it is desired to consider the application of runner A to a plant in which the turbines are to be single runner having a capacity of 15 000 HP each under a normal head of 50 ft. and that the head is at times reduced to 30 ft. by flood conditions. In the latter case, water is plentiful, and the main consideration is power, regardless of efficiency. It is desired to determine whether this runner is applicable to these conditions, and, if so, at what speed it should run.

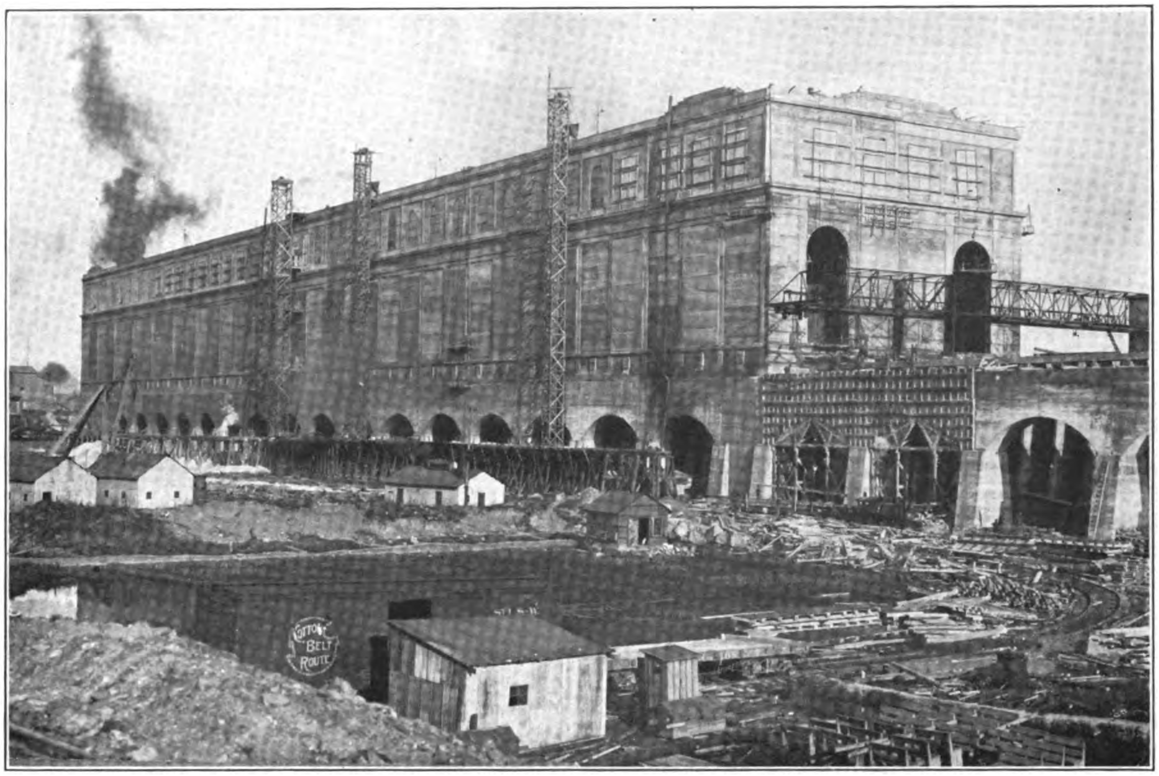
There are two fixed conditions desirable to fulfil:

(a) The wheel should develop its maximum efficiency at 50 ft. head. The test shows that in order to do this it must run at $\phi = 0.780$.

(b) The specific speed of the wheel should be a maximum at 30 ft. head. The test shows that in order to accomplish this it must run at $\phi = 1.100$.



SPEED RING FOR 10 800 HP CEDARS RAPIDS TURBINE ON BORING MILL



POWER HOUSE OF THE MISSISSIPPI RIVER POWER CO. DURING CONSTRUCTION

TEST DATA

It now remains to be seen how nearly this particular wheel will satisfy both conditions.

If $\phi=0.780$ at 50 ft., then it follows that at 30 ft.

$$\phi=0.780\times\frac{\sqrt{50}}{\sqrt{30}}=1.007$$

This value is not as high as it should be to satisfy (b), but the specific speed, which has a maximum value of 130.5 at $\phi=1.100$, drops to only 125 at $\phi=1.007$. In order to satisfy (b) it would be necessary to increase ϕ at 50 ft. to

$$\frac{0.780\times 1.100}{1.007}=0.852 .$$

which would entail a loss of about 1.5% efficiency under normal operating conditions. It would seem better to make a slight sacrifice of power under extreme flood conditions, and let $\phi=0.780$ at 50 ft.

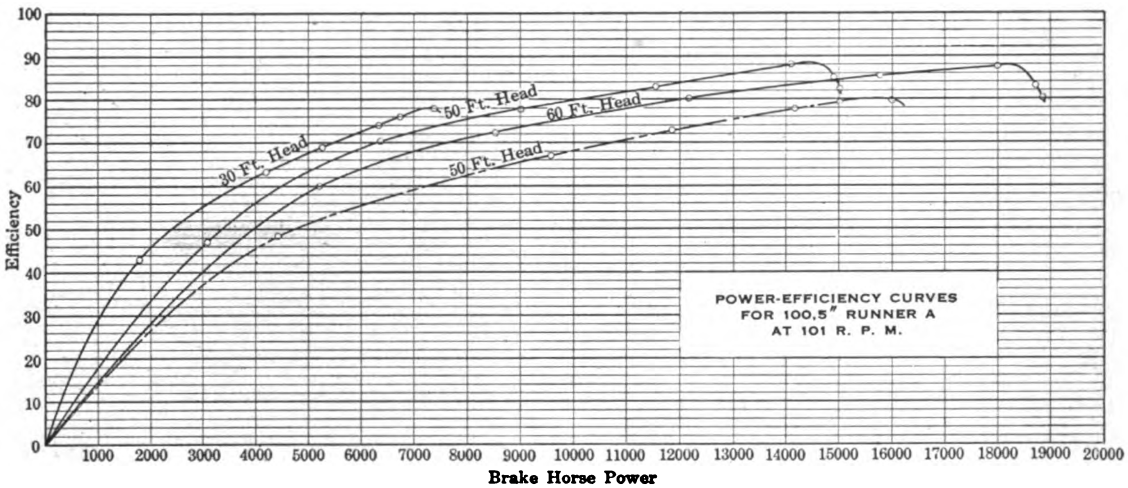


FIG. 2

TEST DATA

Now, $\phi = \dfrac{N \times \pi D}{720 \times \sqrt{2gH}}$ therefore, $N = \dfrac{720 \times \sqrt{2gH} \times \phi}{\pi D}$

The maximum power shown by the test at $\phi = 0.780$ is 2.22 HP, and therefore

$$D^2 : 23^2 = \frac{15000}{50^{\frac{3}{2}}} : 2.22$$

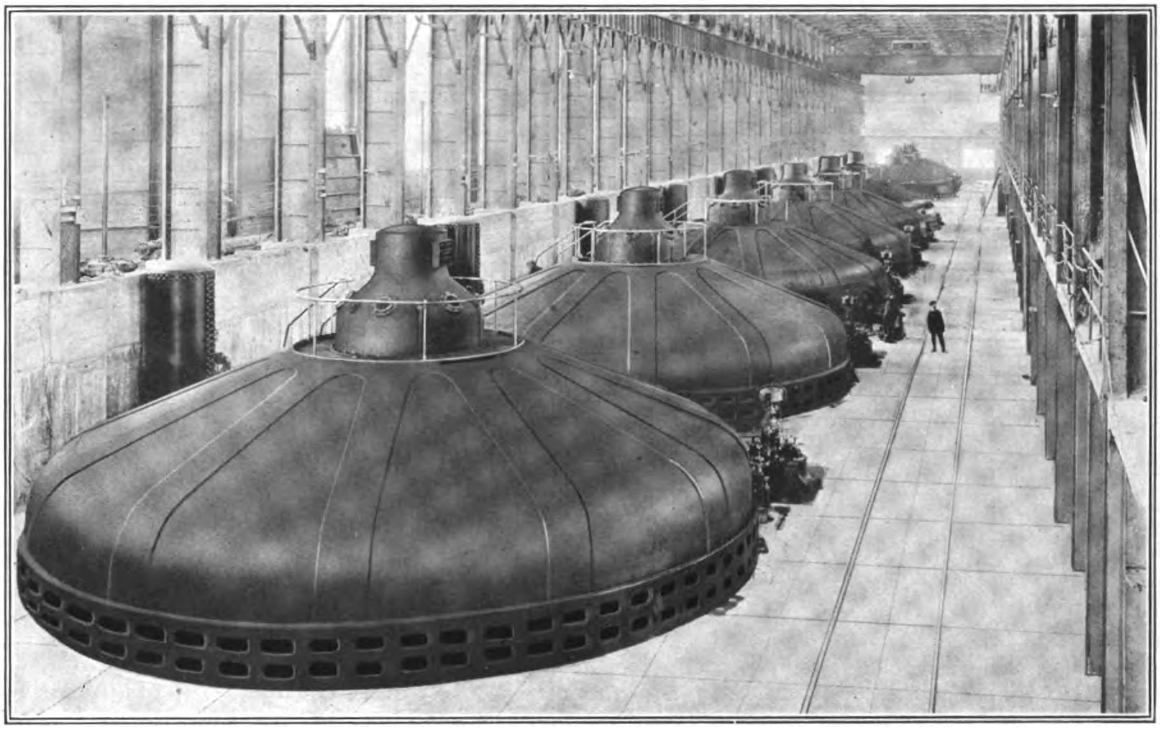
$D = 100.5''$ and by substitution $N = 101$ RPM

Since at 30 ft. $\phi = 1.007$ and the HP curve Fig. 1 shows a maximum value of 2.37 at this speed, then the power at 30 ft. will be

$$P = \frac{2.37 \times 30^{\frac{3}{2}} \times 100.5^2}{23^2} = 7440 \text{ HP}$$

Fig. 2 shows the power-efficiency curves for the heads of 50 ft. and 30 ft., and an additional curve for 60 ft., assuming that to be the maximum head.

The above analysis serves to illustrate the method of using Holyoke tests. The best speed of the wheel is shown to be 101 RPM, and even though it might be advisable to sacrifice efficiency somewhat in order to increase the speed, it cannot be done to any material extent without considerably reducing the output at 30 ft., and the power at that head will in all probability be the limiting condition.



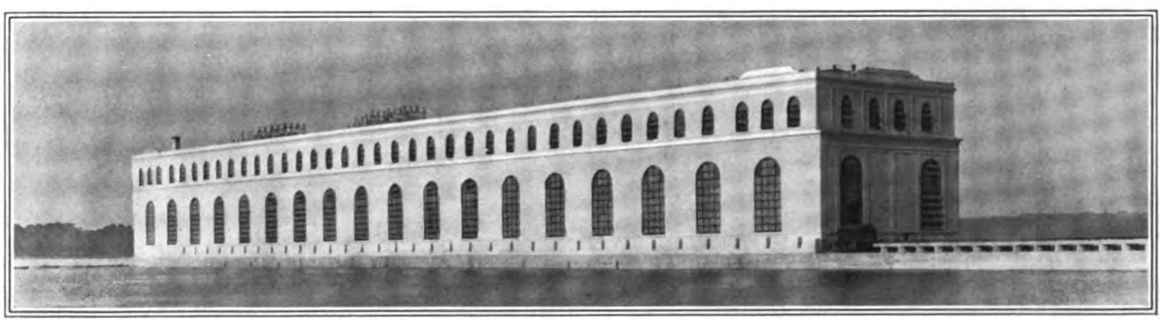
POWER HOUSE CEDARS RAPIDS MFG. AND POWER CO.

TEST DATA

If, however, the minimum head were only slightly lower than the normal, the problem might be changed. Peak efficiency drops to 80% at $\phi = 0.978$, and if it were permissible to have the efficiency that low, the speed might be increased to $\frac{101 \times 0.978}{0.780}$ $= 126.6$ RPM

The curve for this speed is shown by broken lines in Fig. 2.

Thus far only peak efficiency has been considered. Naturally, however, the shape of the efficiency curve must be carefully studied in relation to the load characteristics of the



150 000 HP PLANT OF THE MISSISSIPPI RIVER POWER CO., KEOKUK, IA.

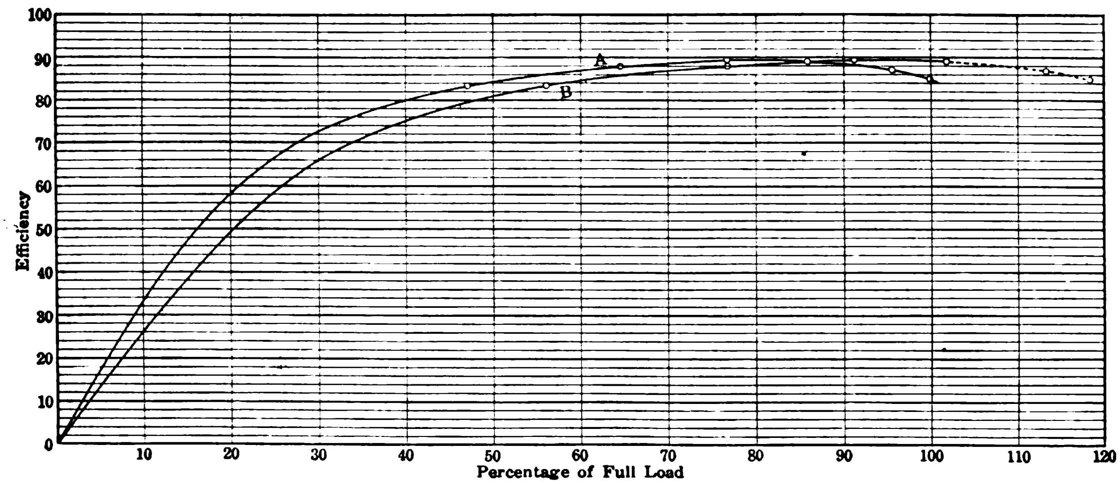


FIG. 3.—COMPARATIVE CURVES FOR TWO RUNNERS AT SAME HEAD AND SPEED
A DESIGNED FOR PEAK EFFICIENCY AT 0.80 LOAD AND *B* AT 0.95 LOAD

TEST DATA

plant. If it is a storage proposition with a fluctuating load, the efficiency at low heads may be of the greatest importance. If the number of units is small, part-load efficiency would be very important; but if the number of units is sufficient to permit enough adjustment, the turbines may be kept loaded close to their point of maximum efficiency, even under small plant loads, and part-load efficiency would become relatively unimportant. Again, if the load is constant, low-gate efficiency may be of small importance, regardless of the number of units in the plant. Sometimes it is advisable to have maximum efficiency occur at practically full load. It depends entirely on whether plant conditions are such that the turbines can be operated most of the time at, or near, full load.

Fig. 3 shows two curves illustrating the application of the same type of runner to the same plant. Curve (A) shows the wheel adapted in the usual way, with maximum efficiency occurring at about 0.8 load. Curve (B) shows the same runner applied with maximum efficiency occurring at about 0.95 load. The only difference is that (B) is a larger runner, and the gate stroke is blocked to cut off the drooping end of the efficiency curve. If the gates were opened wide, the rest of the curve would be as shown by the dotted line. It is quite apparent that from 0.90 to 1.00 load, (B) is superior to (A).

The influence of specific speed on efficiency may be observed by a comparison of the various tests illustrated. In general, an increase of specific speed moves the point of maximum efficiency closer to full load, and reduces the efficiency at low loads. If it is forced to the extreme, the result is lower peak efficiency also.

The data for above analysis is given only for purposes of an example. In practice it is not advisable to go to such a high specific speed for a head of 50 ft. A limit of specific speed for any head is reached, where any higher speed is hazardous, due to liability of corrosion of the runners.

For an accurate determination of the best speed for any proposed installation, the turbine manufacturer should be consulted. A generator can be designed for any synchronous speed with very slight difference in efficiency. However, a small change in speed may greatly affect the turbine efficiency.

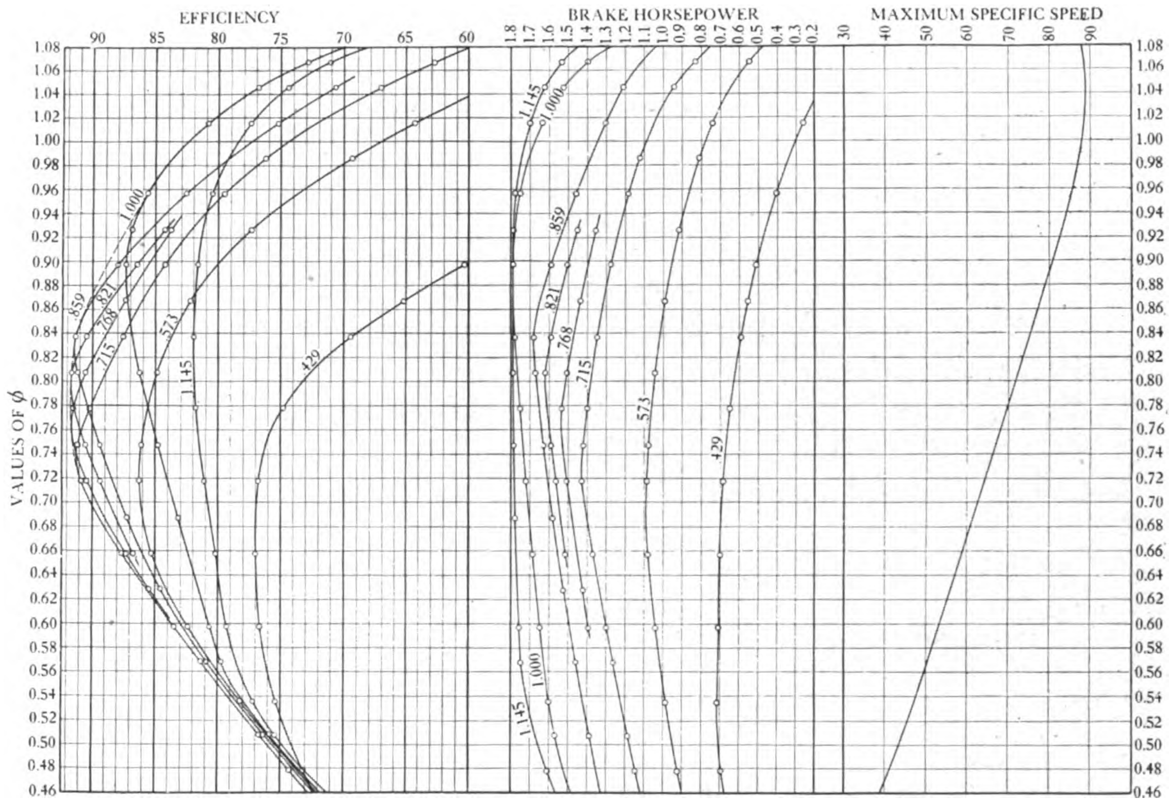
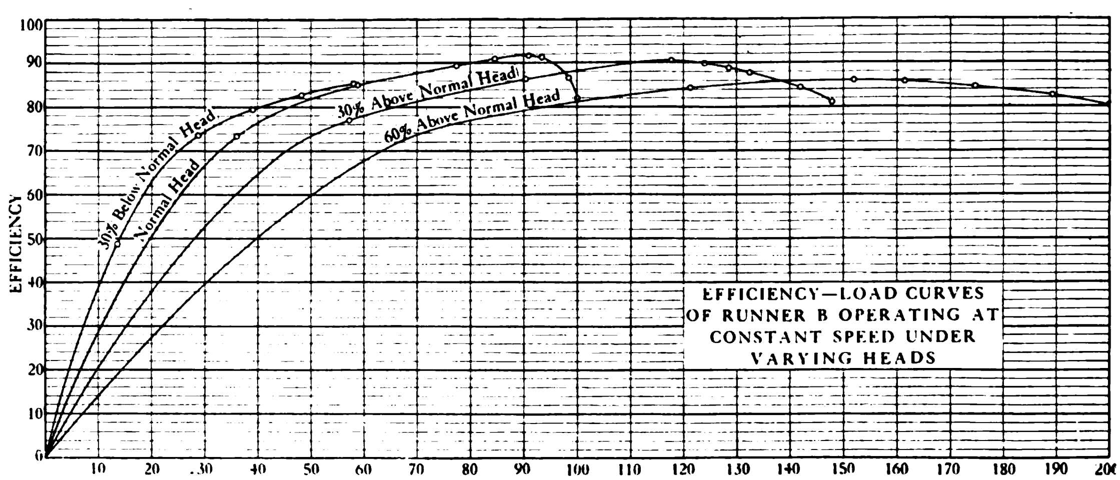


FIG. 4.—HOLYOKE TEST OF EXPERIMENTAL RUNNER B—$N_s = 71.5$



PERCENTAGE OF FULL LOAD UNDER NORMAL HEAD

FIG. 5

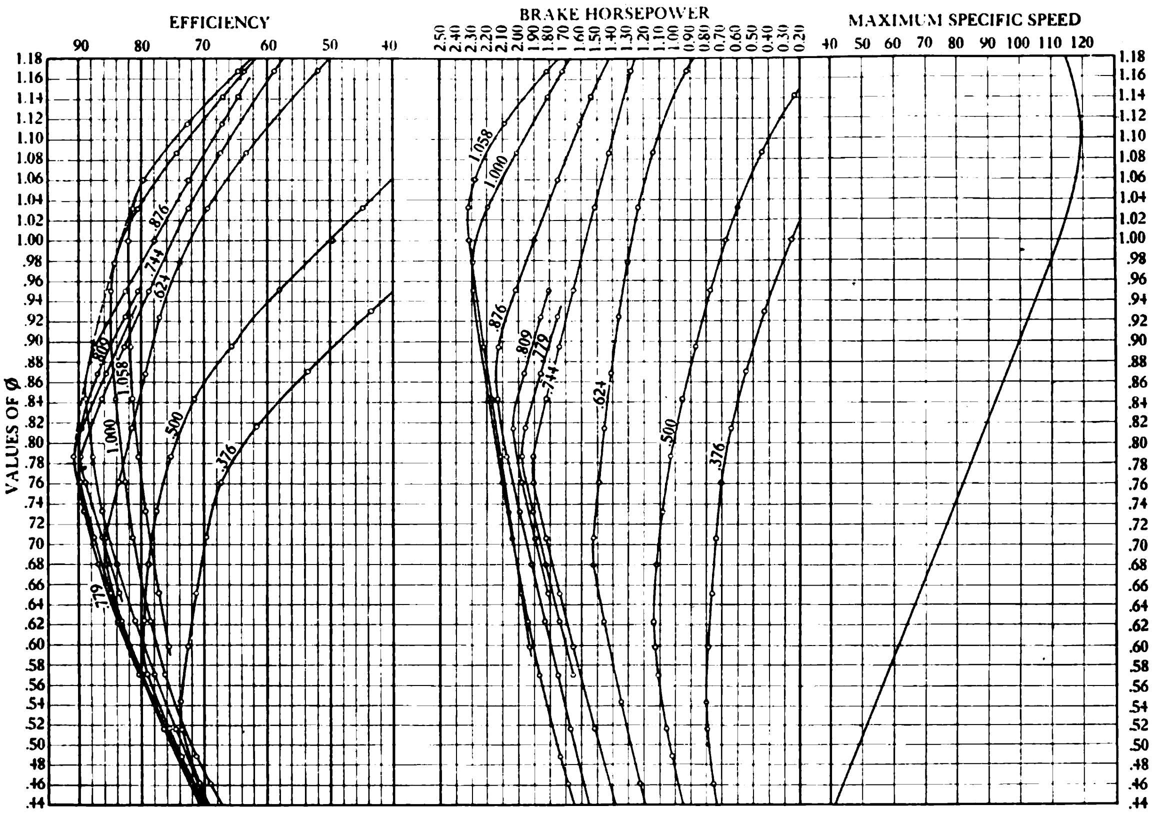
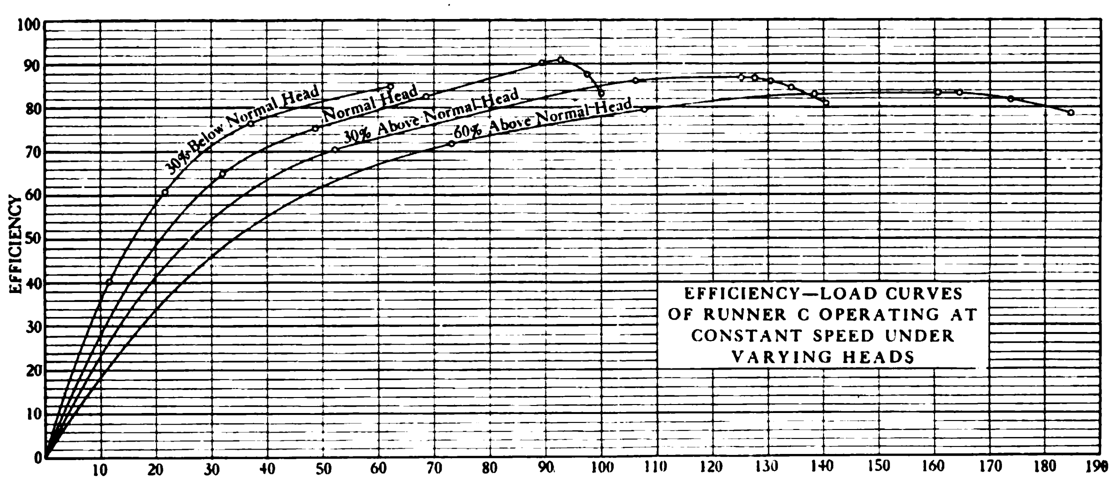


FIG. 6.—HOLYOKE TEST OF EXPERIMENTAL RUNNER C—$N_s=85$



PERCENTAGE OF FULL LOAD UNDER NORMAL HEAD

FIG. 7

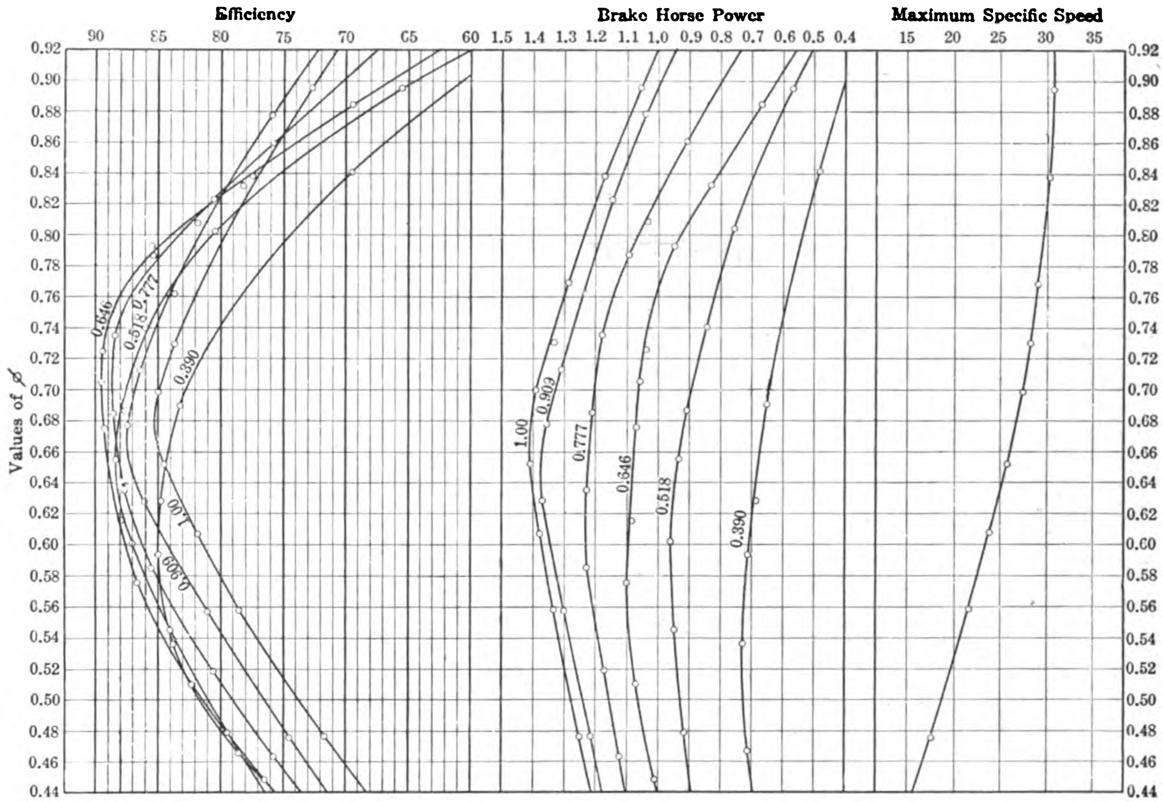


FIG. 8.—HOLYOKE TEST OF EXPERIMENTAL RUNNER D—N_s=27.

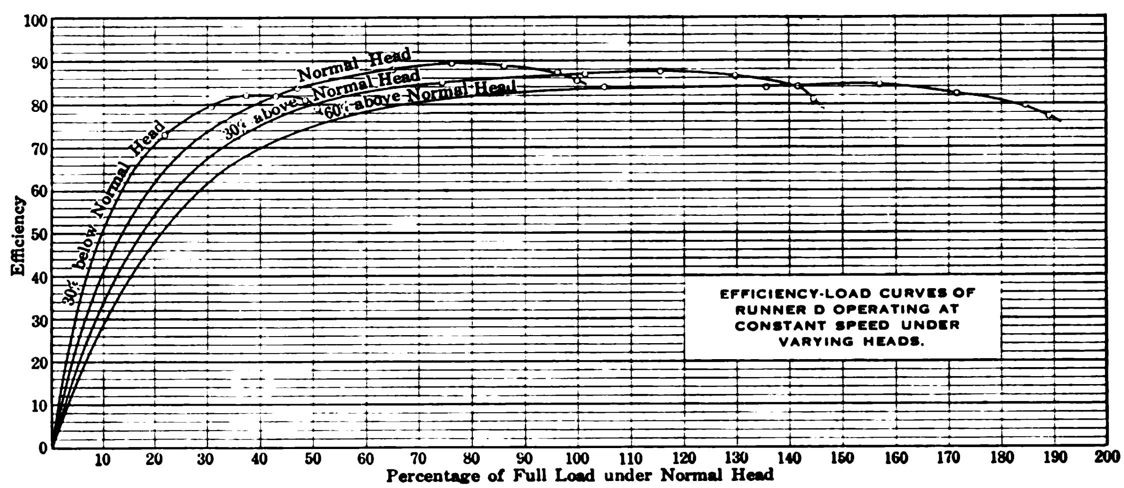


FIG. 9

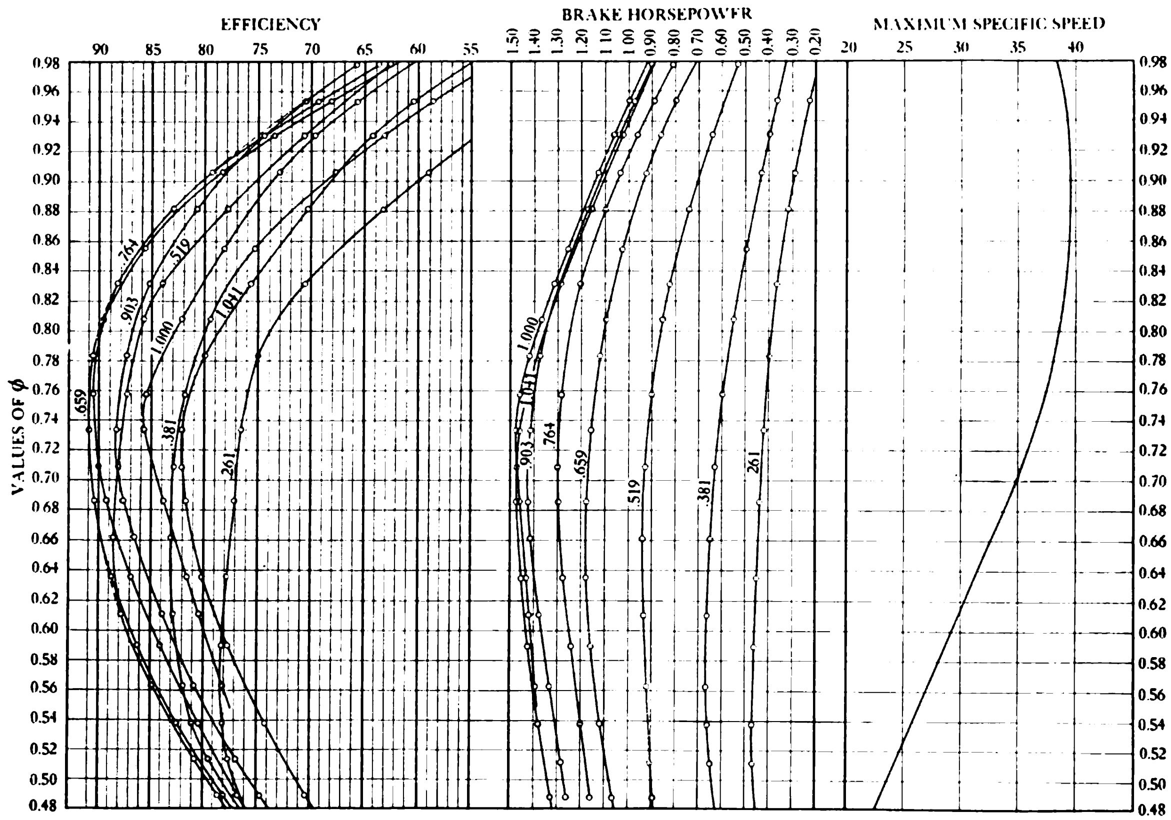


FIG. 10—HOLYOKE TEST OF EXPERIMENTAL RUNNER E—$N_s = 37$

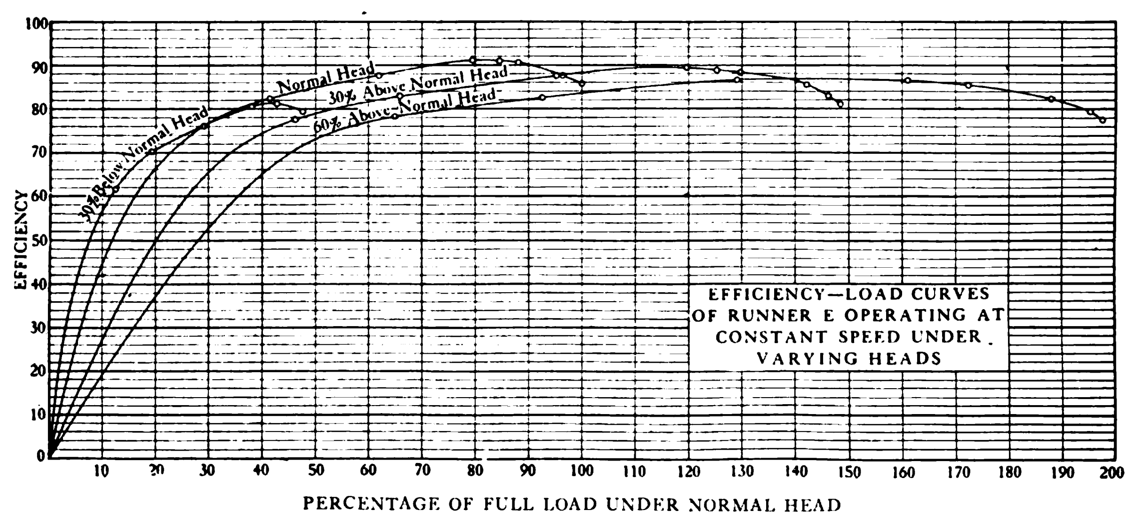
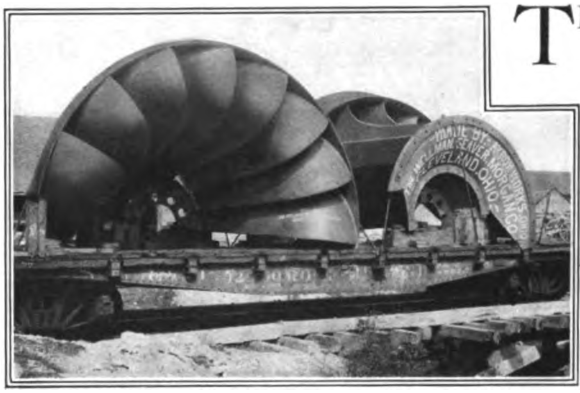


FIG. 11.

PLANT DESIGN

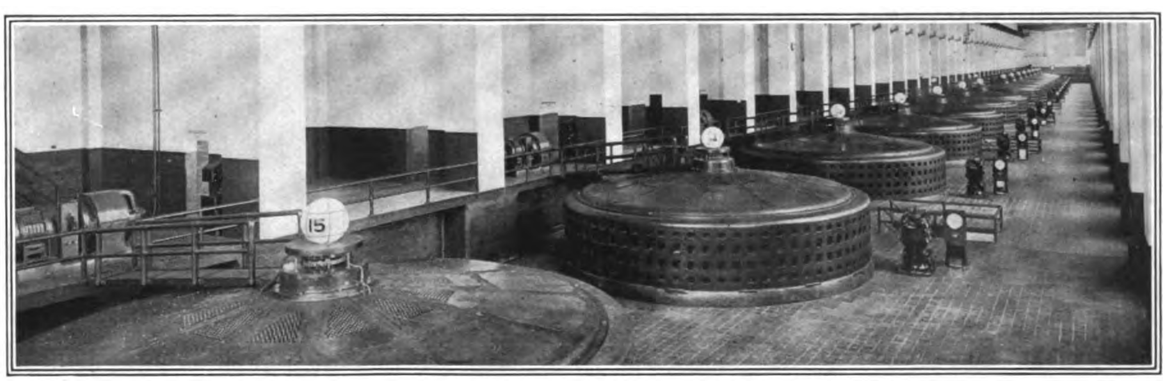


CEDARS RAPIDS RUNNER ON CAR

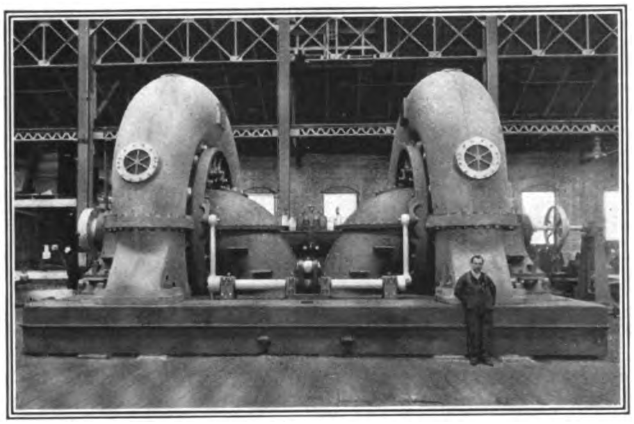
THE design of a hydro-electric plant is so intimately related to the design of the turbines and auxiliaries that the general plan is usually the joint conception of the plant designer and the turbine designer. This is particularly true of some of the more recent installations where the wheel casings, draft tubes and wheel chambers are built in concrete as integral parts of the power house. The controlling factors in the design of the power house are the turbines and generators. The power house is built around the generating units, and hence the general layout is determined by the design of the turbines, and to some extent by the design of the generators.

VERTICAL TURBINES

The vertical unit, although unsuitable under some conditions, is rapidly growing in popularity owing to its manifest advantages over other types. It combines simplicity and accessibility of mechanical parts, with superior efficiency due to an unobstructed draft tube, minimum friction of rotating parts, and convenient application of the spiral casing, which is the most efficient form of turbine casing thus far devised. The merits of the vertical wheel have long been recognized, but its development was greatly retarded by the unreliability of the earlier types of thrust or step bearings. Thrust bearings are now in successful commercial operation on vertical turbines, however, under a wide range of load and speed. They have



KEOKUK GENERATING STATION SHOWING FIFTEEN VERTICAL MAIN UNITS AND TWO VERTICAL EXCITERS



ONE OF TWO 15 000 HP TURBINES BUILT FOR THE ONTARIO POWER CO. OF NIAGARA FALLS

VERTICAL TURBINES

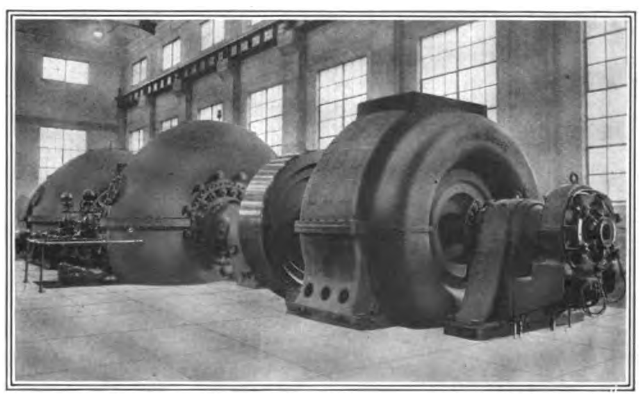
fully demonstrated their reliability, and the greatest obstacle to the development of the vertical unit has thus been eliminated.

Vertical turbines have been built with two or more runners, but experience has shown that they are not desirable. The gate mechanism is almost entirely submerged, and cannot be lubricated. The mechanical design is more complicated, the hydraulic less efficient, and the entire machine is less accessible for inspection or repairs. The only advantage which can be claimed for the multiple-runner vertical unit is higher speed, and that is not sufficient to offset its many disadvantages.

The best practice of today adheres to the single vertical turbine. The casing is of volute or spiral form, and for low heads is usually moulded in the concrete foundations of the power house. For higher heads it is made of cast iron, cast steel or riveted steel plate, as conditions may require. Sometimes the metal casing is imbedded in concrete under the floor which supports the generator, and in other cases it is used as a support for the generator. The thrust bearing is placed on top of the generator, and supported by a spider mounted on the generator frame. The gate mechanism is of the exposed type, no parts being in the water except the gates themselves, and all bearings and pin connections are accessible for lubrication. The gates are operated by two servo-motors or regulating cylinders connected in balance. No gearing or gate shaft is required. The governor is located on the generator floor.

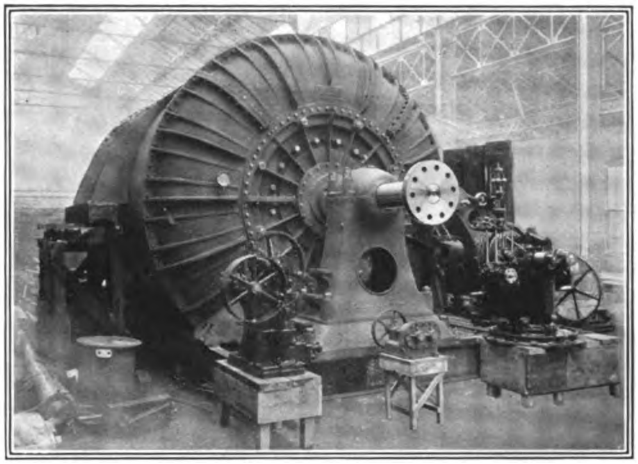
HORIZONTAL TURBINES

Horizontal turbines have been built of almost every conceivable type. Experience, however, particularly in the operation of hydro-electric plants where continuity of service is a prime requisite, has done much to weed out the less reliable types. Many turbines of the open flume type have been built with four, six, and even eight runners per unit. These wheels, however, are open to the same objections which apply to the multiple-runner vertical unit. Too much of the vital mechanism is submerged. It cannot be inspected or adjusted without shutting down the unit, and the usual result is that it is run until it breaks down



PLANT OF THE SALMON RIVER POWER CO. CONSISTING OF FOUR 12 000 HP TURBINES

HORIZONTAL TURBINES

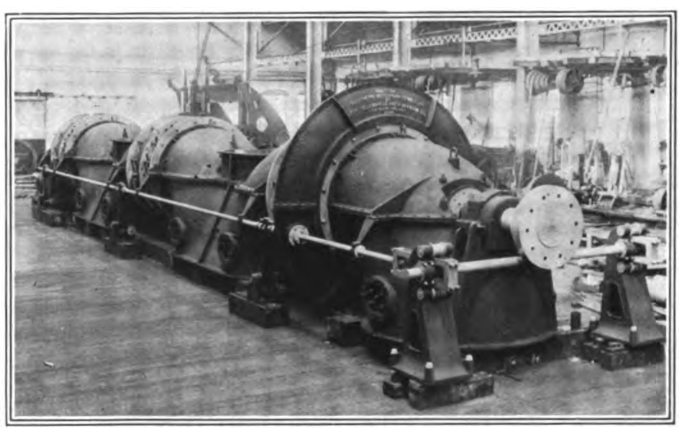


ONE OF TWO 6 000 HP TURBINES BUILT FOR THE CALGARY POWER COMPANY

or gets into such condition that it will no longer run at all. False ideas of economy which inspired engineers to make comparatively insignificant savings in first cost of machinery at a sacrifice of reliability and wearing qualities, are being abandoned, and the demand for turbines that will stand continuous service with nominal cost of maintenance is growing.

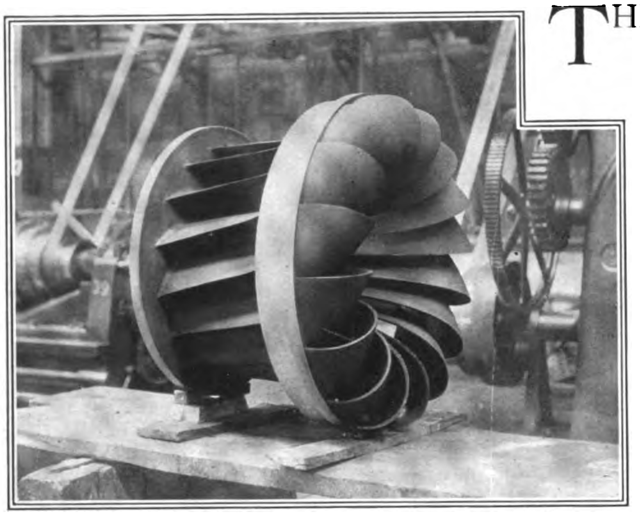
The most approved type of horizontal unit at present is either single or double discharge. Both types admit of exposed gate mechanism. The double discharge has some advantages over the single in that it is hydraulically balanced against end thrust. On the other hand, if it is central discharge (i. e., both runners discharging into a common draft tube), the draft tube conditions are not so favorable. If, however, the runners are spaced well apart, this objection is largely overcome. One of the commonest faults in the design of central discharge turbines as ordinarily built, is the close spacing of the runners.

Horizontal turbines for very low heads are necessarily set in open flumes or wheel pits. For high heads, the volute or spiral casing is the preferable type, the question of central, double or single discharge depending on the conditions to be met. For intermediate heads, the cylindrical plate steel casing has been commonly used. It is not as efficient, hydraulically, as the spiral casing, but it is considerably cheaper. If the penstock connection is at the top or the side, the gate mechanism may be exposed, which is not the case if the penstock is connected at the end. In the latter case, however, the hydraulic conditions are better.



ONE OF FOUR 3 000 HP TURBINES BUILT FOR THE SOUTHERN WISCONSIN POWER CO. THIS TYPE OF INSTALLATION IS SUPERSEDED BY THE LARGE SINGLE VERTICAL TURBINE

DETAILS OF CONSTRUCTION

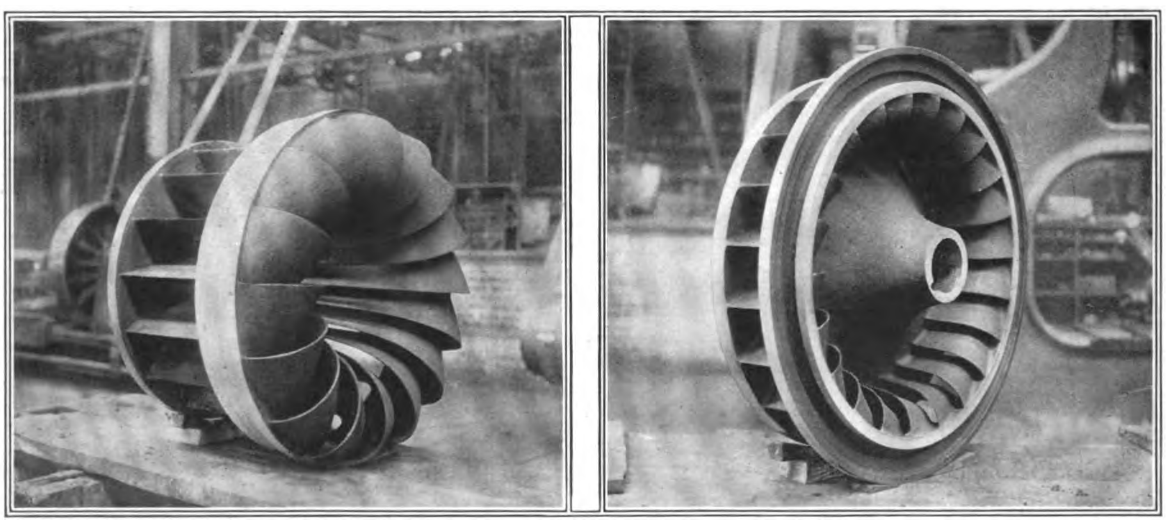


HIGH SPEED TURBINE RUNNER

RUNNERS

THE most important individual detail of a turbine is the runner. Although depending upon other parts for its usefulness, it is the vital moving element upon which everything else depends.

We are prepared to furnish runners of cast iron, cast steel, and bronze. The cost increases in the order named, and the durability likewise. Cast iron and cast steel are the materials ordinarily used for heads below approximately 100 ft. Bronze is generally used for higher heads. The controlling consideration is not strength, but durability, or freedom from corrosion as compared with the cost of the material. It is difficult to generalize on this subject because special conditions frequently upset any general rules which may be prescribed. Thus, for very large runners the cost of bronze is prohibitive, and cast iron or cast steel are used, regardless of head.

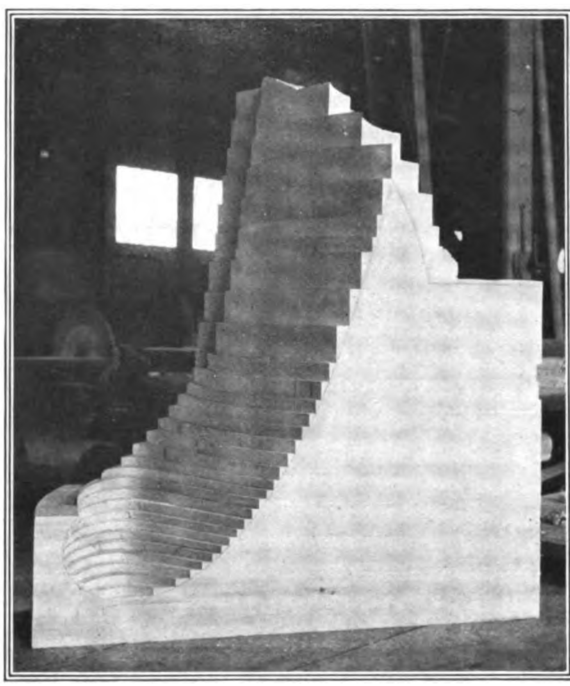


STEEL RUNNERS CAST IN ONE PIECE

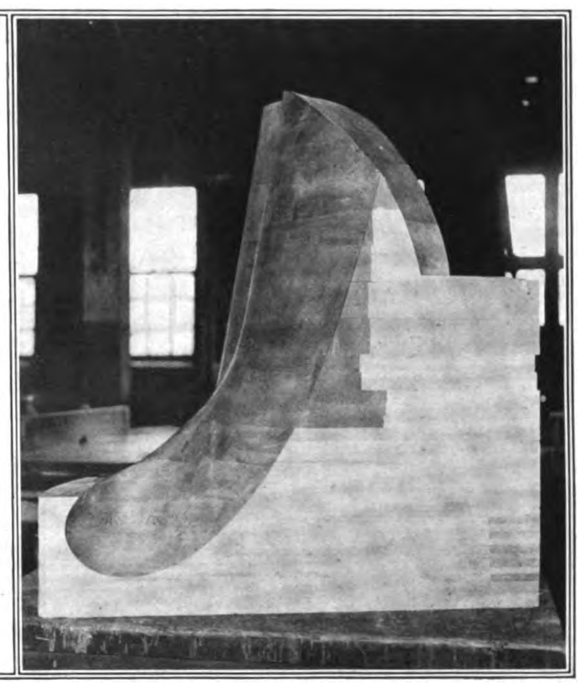
RUNNERS

The relative demand for bronze runners is constantly diminishing. This fact is due to a better understanding of the causes of "erosion." Experience seems to indicate that this phenomenon is of a chemical nature and is nothing more nor less than corrosion. It occurs invariably on those parts of the runner where the design is such that the passing stream of water breaks away from the surface of the metal. This is evidenced by the fact that "erosion" is usually found on the back of runner vanes rather than the front. Any surfaces which curve away from the natural direction of the stream are likely to erode. A void is formed, which fills with air or free oxygen released by the water, and corrosion results. A change in the position of the turbine gates alters the hydraulic conditions in the runner, and the flowing water comes in contact with the corroded surface and washes off the oxidized material. Then the original conditions are restored and more corrosion ensues, followed by the washing process, and so on *ad infinitum*. In time, sometimes very soon, the surface of the metal in such spots becomes pitted. This is the effect of so-called "erosion." The only reason a bronze wheel is any better than cast iron or cast steel, is simply that it does not erode, or rather "corrode," so rapidly.

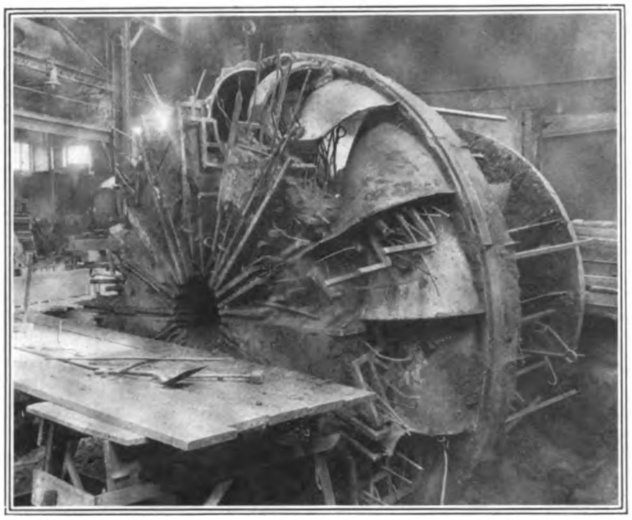
Experience shows that cast iron and steel placed in still water, or water flowing smoothly without disturbance or eddies, oxidizes very slowly. If, therefore, it were possible to design a turbine runner so that, under all conditions of gate opening, the water would flow through it smoothly, without eddies, and at all times in full contact with all surfaces



REAR BLOCK FOR RUNNER CORE-BOX
BEFORE FINISHING



SAME BLOCK FINISHED SHOWING
SHAPE OF RUNNER VANE



KEOKUK RUNNER IN FOUNDRY DURING PROCESS OF CLEANING

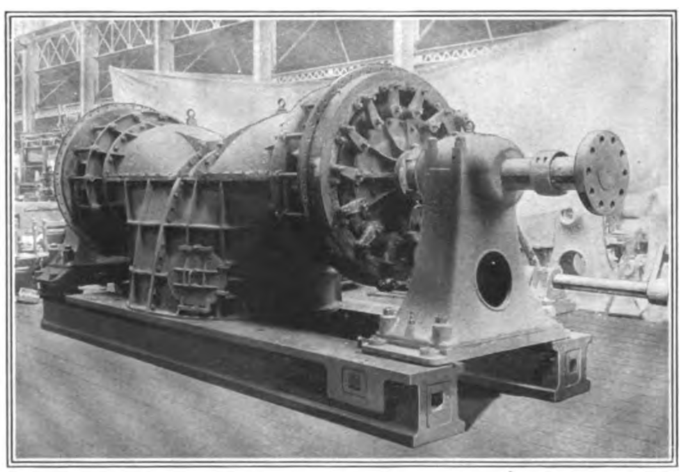
RUNNERS

of the water passages, then we should undoubtedly have a runner which would last indefinitely. This, however, is an ideal condition which the turbine designer has not and never will be able to attain. It is possible to attain it for one particular gate opening, or at best to attain it practically over a limited range, as evidenced by the very high efficiencies now being realized; but until some way is discovered to make runners as efficient at small gate openings as they are at normal load, they will continue to erode. It may not be noticeable under low heads, but it will show under high heads, if the wheels are run much at low gate. The practice so common in many plants, of running units for long periods without load, merely to be ready to take it if it should come on unexpectedly, is particularly bad for the runners.

It must be quite apparent from the foregoing considerations that, other things being equal, the least erosion is to be expected from the most efficient wheel. The higher the efficiency the more smoothly the water passes through the runner, and absence of eddies and other disturbances due to faulty design means freedom from erosion.

Our runners are all cast in one piece from cores. Runners made in this way are stronger, more rigid, and more accurate than those made by any other process. Built-up runners having plate steel buckets or vanes are advocated by some manufacturers because they are lighter and cheaper than solid runners. They lack rigidity and strength, however, and we therefore use only the solid wheel. We have made cast iron runners in one piece weighing as much as 140 000 lbs. each.

Our cast steel runners are made in our own steel foundry, with special equipment and an organization trained for this work. We have made cast steel runners of low specific speed for high head work, in



ONE OF TWO 4 800 HP TURBINES BUILT FOR THE OLYMPIC POWER COMPANY

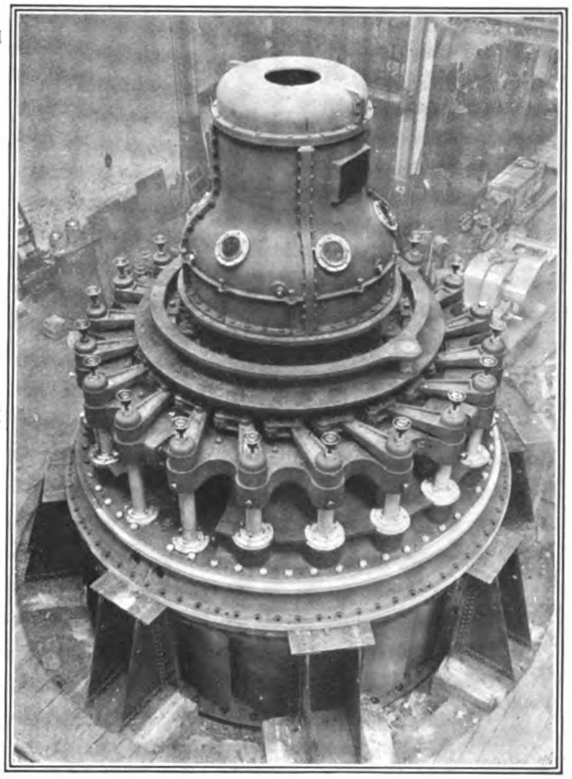
EXPOSED GATE MECHANISM ON A CENTRAL DISCHARGE CYLINDRICAL CASING TURBINE

RUNNERS

common with other manufacturers, and in addition we have gone a step further and made many runners of high specific speed in steel. We are the only turbine manufacturers who have succeeded in making cast steel runners of this type.

GATE MECHANISM

VERTICAL SINGLE RUNNER TURBINE WITH EXPOSED GATE MECHANISM



TOP VIEW OF 10 000 HP TURBINE
FOR THE MISSISSIPPI RIVER POWER CO.

Next to the runner, one of the most important parts of the turbine is the gate mechanism. More moving parts subject to wear and deterioration are embodied in the gate mechanism than in all the rest of the turbine proper. All bearings should, so far as possible, be protected from the action of the water and grit which it contains, and mechanical friction should be reduced to the minimum. The latter consideration is very important, not only because it tends to improve the action of the governor, but because it reduces the wear on the various parts of the mechanism. There are from seventy to one hundred or more separate pin connections and bearings to one set of gates, and replacement of worn parts is necessarily a troublesome and expensive matter. All bearings and pin connections should be lubricated, and this cannot be done properly unless they are protected from the water.

The exposed, or so-called "outside" type of gate mechanism, is much superior to the older types in which the moving parts are more or less submerged. The exposed type, as applied to spiral casing turbines for high heads, is the ideal arrangement in that all bearings may be lubricated and the gate-stem packings may be arranged to exclude water and grit. This is not entirely possible with spiral casing wheels for lower heads where the casing is built of concrete. The lower gate-stem bearing may be lubricated through a hole drilled along the axis of the gate-stem, but it is not possible to pack this bearing against water and grit other than by the flow of grease through it. This method is not as positive as a watertight packing.

The exposed mechanism has a further advantage in that it permits a more direct connection between the operating ring, to which the gate-stem levers are connected, and the regulating cylinders or "servo-motors" of the governor system. When the operating ring is outside the wheel casing, it may be directly attached to the connecting rods of the two regulating cylinders, the connections to operating ring being diametrically

opposite. This is an ideal arrangement. The operation of the ring is then in practically perfect balance. For small vertical units, where the distance from the turbine to the generator floor is not too great, a gate shaft type of construction is less expensive. GATE MECHANISM

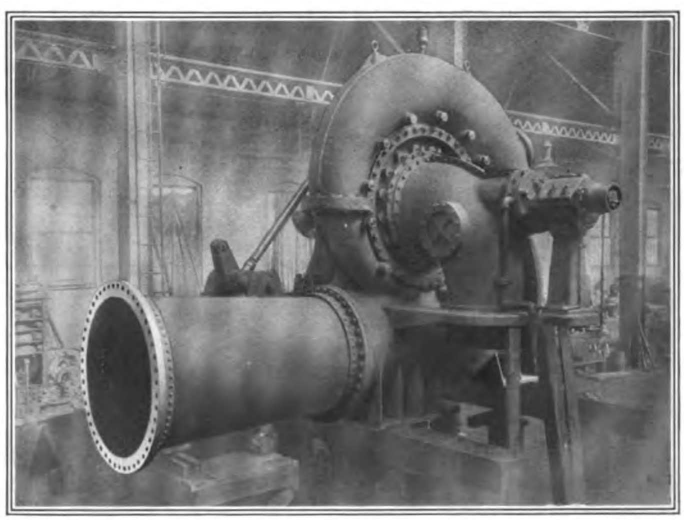
The wicket gates, or movable vanes, should be either cast or forged steel, regardless of the head. They are subjected to rough usage on account of ice, stones and rubbish in the water, and cast iron is too brittle for such service. The gate stems are generally cast or forged integral with the gates.

The gate stems should be of ample strength to resist the strain in case an obstruction is caught between two gates and the full power of the governor is concentrated upon them. The links which connect the gate stem levers to the operating ring should be the weakest element of the gate mechanism. They should be designed to break before the stress reaches the elastic limit of the material of any of the other parts. An adjustment by means of eccentric pins should be provided in order to get simultaneous closure of all gates and equalize the gate opening.

CASINGS

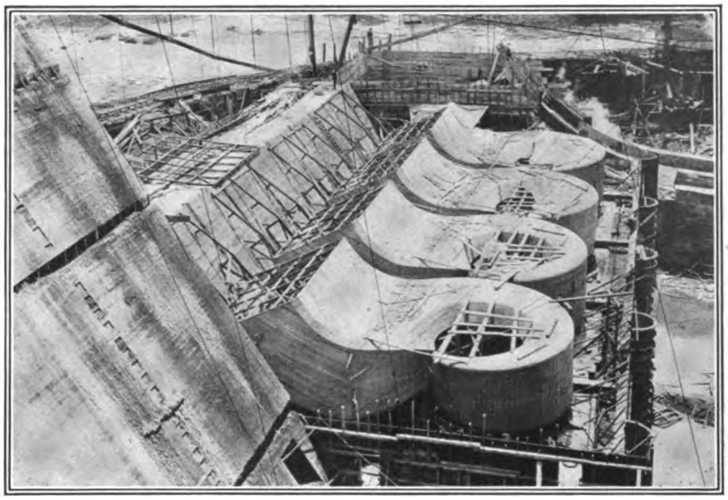
The most efficient form of turbine casing in use at present is that of volute or spiral shape. This type has been in common use under high heads for some years, and is now being adopted with increasing frequency for low heads, particularly where the turbines are of large capacity. The materials most commonly used for medium and high heads are cast iron and cast steel, the choice between them being influenced chiefly by consideration of the stresses imposed. Large casings for high heads are usually made of cast steel. Cast iron, although more suitable for medium heads, may properly be used for high heads if the casings are small and the material is worked at a low stress to provide an ample factor of safety against pressure surges which are of commoner occurrence in high head than in low head plants.

For low heads and especially with large turbines, the casings are usually moulded in the concrete foundations of the power house by means of wooden forms. If the casings are large enough and the head high enough to produce serious stresses in the concrete, they may be made of metal and imbedded in the concrete. The principal controlling factor in this case is the relative cost of such casings as compared with the



6400 HP TURBINE BUILT FOR THE PORTLAND RWY. LIGHT & POWER CO.

CASINGS



WOODEN FORMS FOR REINFORCED CONCRETE
WHEEL CASINGS OF THE HYDRO-ELECTRIC CO. OF W. VA.

cost of adequate reinforcing steel for the concrete, which would be required if the metal lining were omitted.

Another important point to be considered, however, is the problem of making a water-tight joint between the concrete and the turbine structure if no lining is used. This difficulty becomes more serious as the head increases, and is of course eliminated by the use of a metal lining.

The commonest type of turbine setting in the early days of water-power development was the vertical wheel set in an open pit, usually of rectangular form. The early installations were crude and defective, aside from the apparatus itself, in that the wheel pits were made too small and the draft tubes were too short and poorly designed. That this type of setting may be made very efficient, however, is amply demonstrated by the Holyoke testing flume, where efficiencies in excess of 90% are not infrequently obtained. The Holyoke flume has an open rectangular wheel pit, but it is unusually large in proportion to the size of the experimental wheels now tested there. The velocity in the flume is very low, the water being drawn to the wheel practically from a state of rest. This is a favorable condition, although experimental data appear to indicate that it is not quite as favorable as the condition in a volute casing where the water enters at a given velocity and is delivered to the guide passages in a direction approximately coincident with the guides.

It is not the purpose here to discuss the reasons for the evolution from the old style vertical wheel to the various types of horizontal setting and then back to the modern vertical installation. These reasons are set forth under other headings. It is sufficient here to say that the design of the casing has been an influential factor. It was not considered as important in the first instance as the desire for higher rotational speed, but it was one of the dominating influences in the succeeding transition, as evidenced by the fact that high speed has been sacrificed to get an efficient wheel casing. Of course, there are other important reasons for the adoption of the modern vertical design, but none of them is more important than the favorable opportunity afforded in this design for the use of the volute casing.

Other forms such as the horizontal cylindrical casing, and the open flume of restricted proportions must be regarded as compromises dictated by a desire to save on first cost. They are all more or less inefficient, due to sudden changes of velocity and direction, obstructed flow, and improper guidance of the water. The tendency is

away from such types of construction, and undoubtedly many of these plants will be remodeled and modernized in the near future.

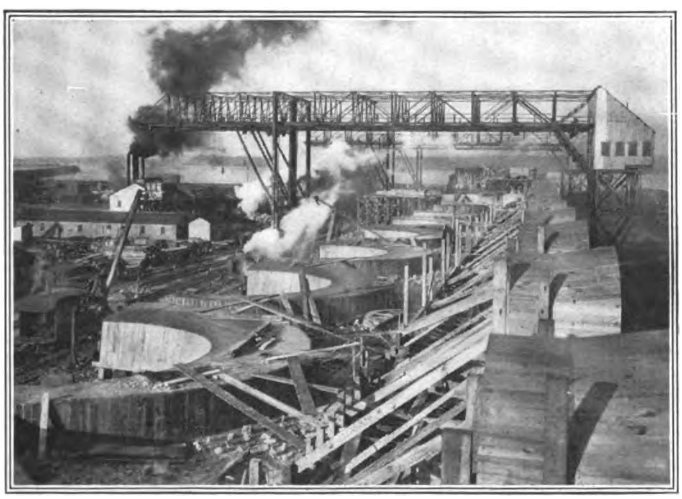
KEOKUK DRAFT TUBE FORMS

DRAFT TUBES

The importance of correct draft tube design, as a factor in the efficiency of the turbine as a whole, was not generally appreciated until within recent years. Even now it often does not receive due consideration. The velocity of the water as it leaves the runner and enters the draft tube represents a considerable part of the available energy. The function of the draft tube is to recover this energy and convert it into work. Thus the draft tube plays an important part in the performance of the turbine.

The upper end of the draft tube should fit accurately to the band of the runner. The wall of the tube at this point should be a continuation of the inside surface of the runner band. The tube should be long enough to reduce the velocity to a proper value without too rapid enlargement of cross section. At the same time it should not be so long that the inertia of the column of water in the tube is sufficient to break the vacuum when the flow is suddenly checked by the closing of the turbine gates.

Good draft tube design is fundamentally dependent upon the proper elevation of the turbine above tail water. The runner should be so located that the total draft head at the top of the tube is well within the theoretical limits of a vacuum; namely, approximately 34 ft., depending on the barometer reading.



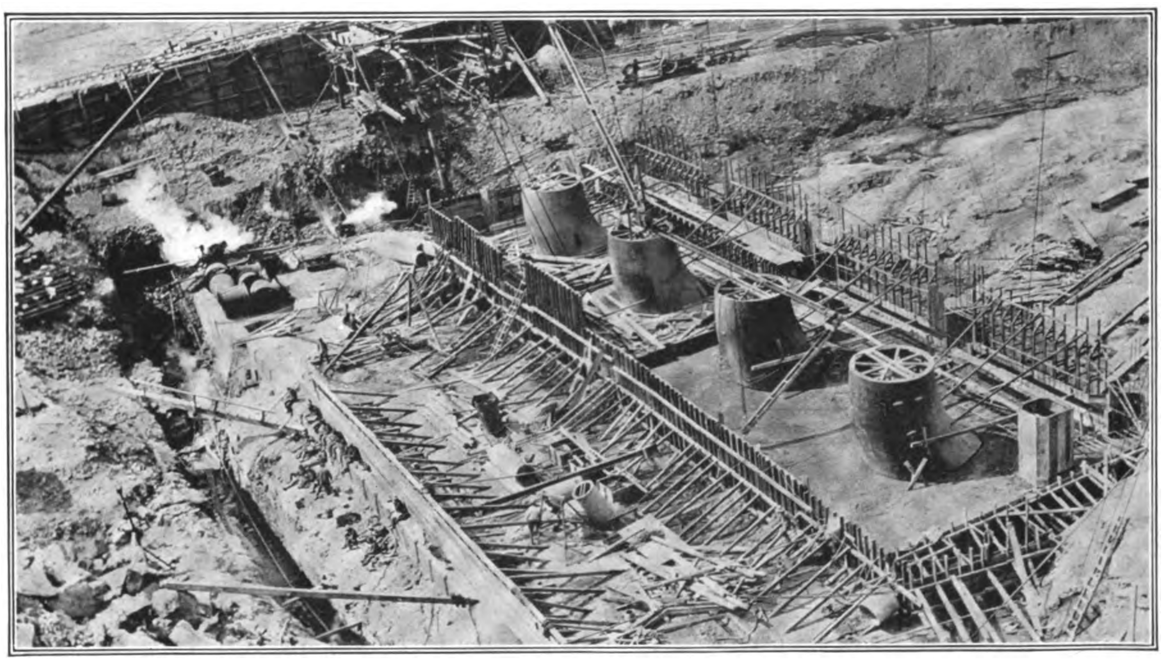
WOODEN FORMS FOR CONCRETE VOLUTE WHEEL CHAMBERS AT KEOKUK

The total draft head at the top of the tube, friction being negligible, is the vertical elevation, H_e, of this point above tail water plus the head represented by the velocity of the water at that point. The latter is the so-called "velocity head", $H_v = \frac{V^2}{2g}$. It is safer to base the calculations on the cross section at the top of the runner band rather than the top of the draft tube, because the draft head actually extends well into the runner.

DRAFT TUBES

The difference between the barometer reading and $H_e + H_v$ is the margin of safety allowed for contingencies, the most important of which is the additional vacuum caused by the inertia of the water column in the draft tube when the turbine gates close. Whenever a portion of the load on the turbine is dropped, the governor closes the turbine gates proportionately in order to maintain constant speed. If the continuity of the water column in the draft tube is to be maintained, the velocity must be correspondingly reduced as rapidly as the gates close. The vacuum H_i, at the top of the draft tube, necessary to overcome the inertia of the water column therein, is the same as the pressure which would be required if the retarding force were applied at the bottom of the tube. This is readily calculated on the basis of any assumed rate of governor action, and should be carefully considered in determining the elevation of the turbine. The maximum value of $H_e+H_v+H_i$ should be less than the barometer reading, or the column of water in the draft tube will break, returning with a surge and causing a water hammer.

It should be noted that whereas H_e is a constant, H_v and H_i are both variables, and the maximum value of the term (H_v+H_i) is best determined graphically. The worst condition to be considered is that of a shut-down from full-load discharge to only sufficient water to keep the wheel running at speed with no load. Curves of H_v and H_i should be plotted for a shut-down with time of gate movement as abscissae and the maximum value of (H_v+H_i) determined therefrom. The curve of H_i increases from the beginning of the gate stroke to the end, whereas H_v decreases. The maximum values of H_v and H_i are not coincident, and hence cannot be calculated independently and added together. In practice, the sum of these three terms should be kept safely below the theoretical limit. If the vacuum in the draft tube is near the breaking point, continuity of flow may be interrupted at the discharge end of the water passages through the runner, resulting in corrosion and pitting of the vanes.



DRAFT TUBE FORMS PARTLY CONCRETED—HYDRO-ELECTRIC CO. OF WEST VIRGINIA

DRAFT TUBES DURING CONSTRUCTION
RUMFORD FALLS POWER CO., RUMFORD FALLS, MAINE

DRAFT TUBES

The effective length of the draft tube extends to the point where the discharge is released to atmospheric pressure. This fact may be utilized to advantage where it is impossible for any reason to make the draft tube as long as it should be to reduce the velocity at exit to a proper value. In such cases the tail race may sometimes be sealed to the atmosphere and the residual loss is then the velocity at exit from the tail race rather than from the draft tube. Of course such an arrangement is not as efficient as a properly designed draft tube, because there is a loss at the point where the draft tube discharges into the tail race.

The residual velocity at the point where the discharge is released to the atmosphere is an irreclaimable loss and should be made as small as possible. The fact that this loss is not chargeable to the turbine should always be taken into account in making efficiency tests.

It used to be common practice to make all draft tubes of steel plate, but of late years they are usually moulded in the concrete foundation of the power house, except in the case of small turbines. It is not feasible to build large draft tubes entirely of plate, nor is it possible to obtain the smooth curves and efficient design characteristic of concrete tubes.

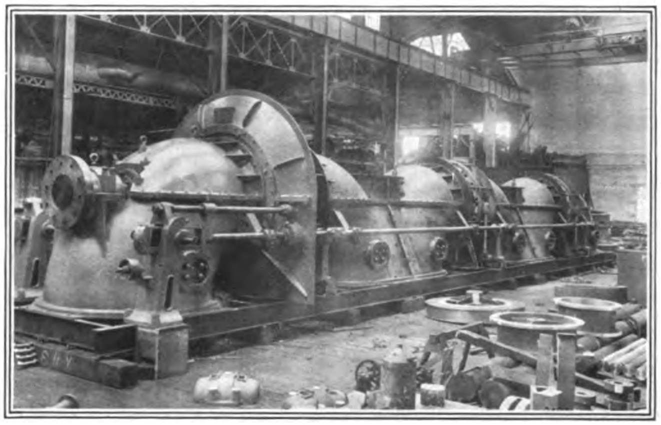
The upper part of the draft tube should be lined with steel plate to prevent pitting of the concrete. This is especially necessary if the velocity at the top of the draft tube is high and the vacuum is near the breaking point. For small turbines a straight conical draft tube can often be used and the velocity decreased sufficiently at the lower end without too great an angle of flare. This form of draft tube is the most efficient of any. However, large draft tubes of this type, in order to maintain the proper angle of flare with a maximum reduction in velocity, would be extremely long and would entail too great an expense for excavation.

As a result of three years of experimental work, we have succeeded in developing a draft tube design for large units which shows a greater regain in energy than any other known design, with a minimum spacing of units.

SHAFTS

The duty imposed upon a turbine shaft in many cases is unusually severe. The shaft of a vertical turbine need be proportioned only for the power transmitted, with proper allowance for bending stresses due to indeterminate unbalanced effects in the

SHAFTS



6000 HP TURBINE BUILT FOR THE SANITARY DISTRICT OF CHICAGO

rotating parts, and stiffness to resist vibration. The shaft of a horizontal turbine, however, must be proportioned to support its own weight and the weight of the runners, in addition to the other requirements. In some cases the runners are placed midway between the bearings at the point of maximum deflection. The shaft must be large enough to reduce the deflection to a negligible value and to keep the maximum bending stress, due to combined torsion and flexure, within safe limits. The working stress should be carefully considered in relation to the physical and chemical characteristics of the material used, in order that proper provision may be made against crystallization. A horizontal rotating shaft is subject to constant reversals of stress, and will probably crystallize and break unless the combined bending stress is low and proper material is used. Due consideration should also be given to the relation between the runaway speed of the turbine and the so-called "critical speed" of the shaft. The critical speed is a mathematical function of the deflection and signifies the speed at which the normal deflection of the shaft begins to increase, due to centrifugal force, or in other words, at which the shaft begins to "whip". The critical speed should be well above the runaway speed.

The question of suitable material is too broad to be discussed in detail. Open hearth carbon steel, annealed and sometimes heat-treated, is ordinarily used. Alloy steels are occasionally required where, for structural or hydraulic reasons, the size of the shaft must be restricted. Very large shafts are usually hollow bored, not so much to reduce weight as to insure sound forgings. Forged flanged couplings are preferable to keyed couplings.

BEARINGS

Main shaft bearings may be divided into two general classifications:—babbitted bearings with oil lubrication, and lignum-vitae bearings with water circulation and sometimes grease lubrication.

Horizontal bearings of either type are self-aligning and adjustable in height as well as position. Babbitted bearings, if accessible, are ring-oiling; otherwise they are lubricated by forced-feed. All large oil-lubricated bearings are water-cooled. This feature is not usually required in ordinary operation, but is valuable in case of emergency. Lignum-vitae bearings are provided with a filtered water supply and may be equipped with forced-feed grease lubrication, if desired. Horizontal lignum-vitae bearings are not recommended if it is practicable to use babbitted bearings. They are not safe unless frequently and systematically inspected.

BEARINGS

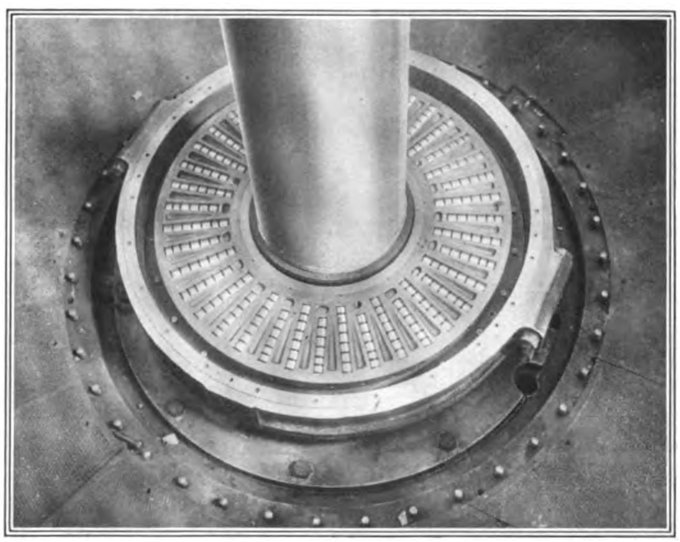
Vertical babbitted bearings are ordinarily lubricated by gravity oil feed. Oil is supplied from a reservoir situated above the turbine, to which it is returned by a pump after draining from the bearings. This type of bearing is best adapted for positions intermediate between the turbine and generator, provided such bearings are required. Vertical units of customary design, however, require no intermediate bearings. Unless the shaft is exceptionally long, the only guide bearings required are one on top of the generator, one immediately below the generator rotor and one on top of the crown plate of the turbine.

The bearing on the turbine is usually lignum-vitae. It may be placed closer to the runner than an oil bearing, is simpler, requires less attention, and is equally efficient. Furthermore, the duty required of a vertical guide bearing on a well balanced turbine is so light that lignum-vitae will not wear appreciably in many years of service.

Thrust bearings for horizontal units are usually of the marine type with the thrust collars forged on the shaft. They are self-aligning, ring-oiling and water-cooled, and are substantially braced or tied to the turbine head. These bearings are designed only to carry the residual thrust of the turbine. In the case of a single discharge turbine the principal part of the thrust is carried by an automatic hydraulic thrust piston or an arrangement of balancing chambers around the runner.

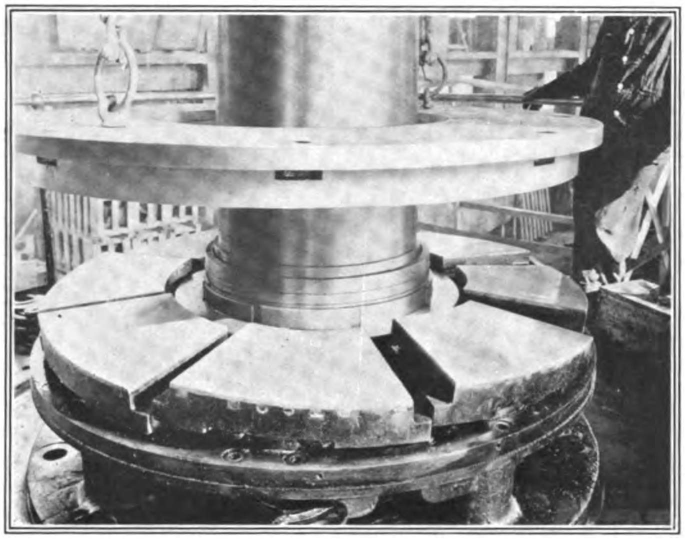
Several types of thrust bearing have been successfully used on vertical turbines. The oldest type for large units and heavy loads is the oil pressure bearing introduced a number of years ago at Niagara Falls. In this bearing the thrust discs have a large annular groove into which oil is forced under pressure. The pressure used is sufficient to lift the rotating parts slightly, permitting the escape of oil between the faces of the discs which would otherwise be in contact. Thus the load is carried on a film of oil. The disadvantages of this type of bearing are the expensive and troublesome auxiliaries required to furnish the oil pressure, and the certainty of serious damage if the oil pressure fails while the turbine is in operation.

Roller bearings are simple to operate and have been successfully used under a great variety of conditions. Extreme accuracy is indispensable in their manufacture, and the material used must be uniform and of the highest grade. They are run in an oil bath, the oil being filtered and circulated by gravity from an overhead reservoir.



ROLLER BEARING FOR 10 000 HP TURBINE
BUILT BY THE STANDARD ROLLER BEARING CO.

BEARINGS



KINGSBURY THRUST BEARING FOR CEDARS RAPIDS MFG. & POWER CO.—LOAD, 550 000 POUNDS

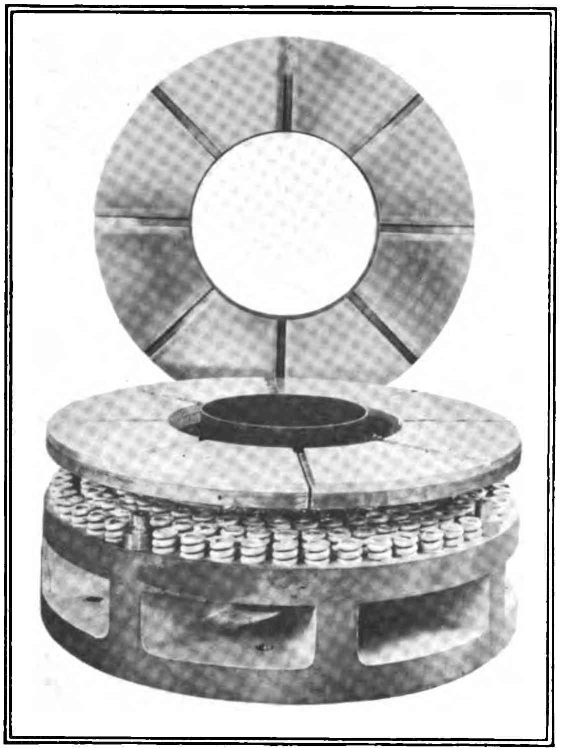
Roller bearings for large units are constructed in some cases to incorporate the oil pressure feature also. The latter is combined with the rollers in such a manner that the weight may be lifted off the rollers for ordinary operation and carried by them only in the event that the pressure should accidentally fail. Or it may be carried ordinarily on the rollers, the pressure being held in reserve in case of trouble with the rollers. Several of the largest plants in the country are equipped with this type of bearing.

The Kingsbury bearing manufactured by the Westinghouse Co. is a contact bearing which runs in an oil bath, the weight being carried on a set of segmental babbitted shoes. A liberal space is provided between adjacent shoes to permit free circulation of oil. Each shoe has a single pivot support located toward one end of the shoe, slightly beyond the center of gravity in the direction of rotation. This arrangement causes the space between the shoe and the thrust block on the shaft to open slightly at the other end of the shoe, where the oil is drawn in by the rotation of the thrust block. The film of oil on the face of the shoe thus assumes the form of a very fine wedge constantly urged forward by the rotation of the thrust block. This action insures perfect lubrication without grooves, and sustains the high oil pressure between the bearing surfaces necessary to carry the heavy weight imposed. This bearing may be operated with surface pressures of 400 to 500 pounds per square inch. A considerable excess of area must be provided, however, to take care of the starting and stopping conditions, which are much more severe than the running condition.

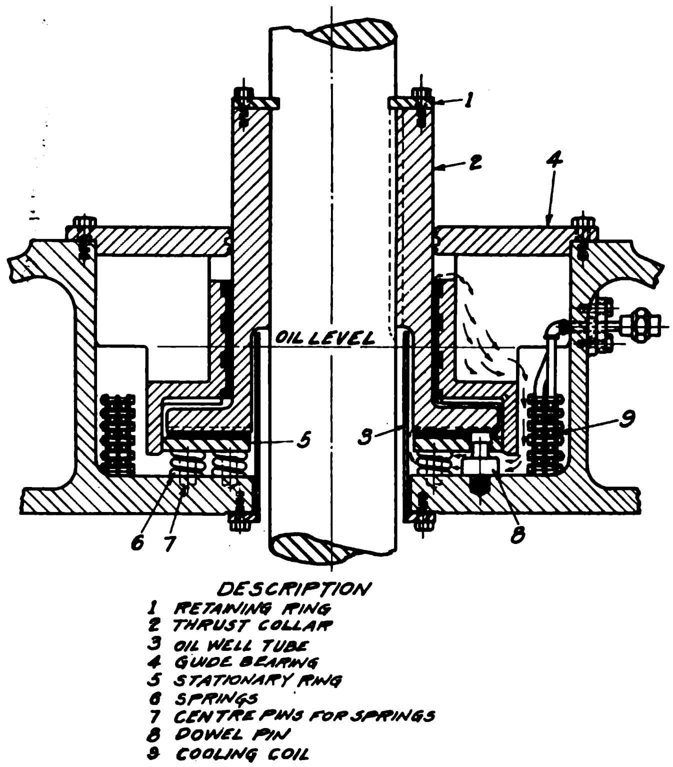
The pivots which support the shoes are individually adjustable for height. Any or all of the shoes may be removed and replaced without dismantling the unit or disturbing the shaft. It is only necessary to open up the thrust bearing housing.

The spring thrust bearing manufactured by the General Electric Company is the latest type in common use on hydro-electric generating units. The distinctive feature of the spring supported bearing is that it will automatically adjust itself while in operation, if there is a loss of alignment due to the settling of the foundation, or to other causes. Further, the yielding support is claimed to allow for any inaccuracies in the finishing of the several parts, which feature is important since the oil film between the surfaces of a thrust bearing is only about three ten-thousandths of an inch in thickness.

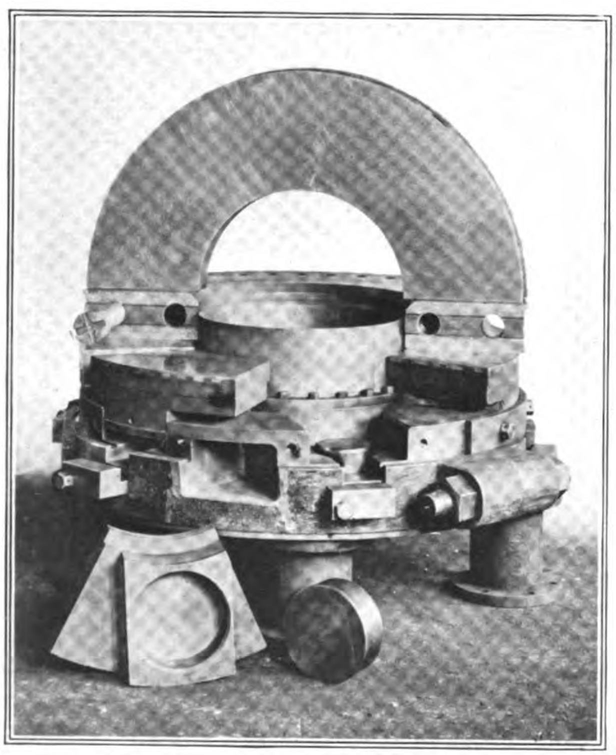
The bearing consists of a runner of a special grade of cast-iron resting on a thin steel disk with a babbitted surface. This babbitted ring, in turn, rests on short helical springs and is held in place by dowel pins. The high base casting is used in connection



GENERAL ELECTRIC SPRING SUPPORTED THRUST BEARING FOR 7500 KVA VERTICAL GENERATOR, THRUST 276,000 LBS.



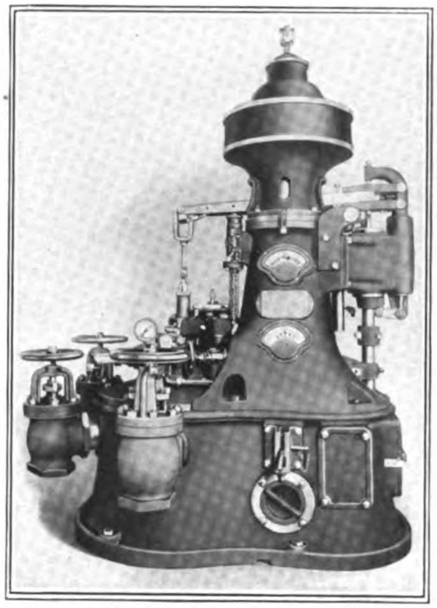
GENERAL ELECTRIC COMBINED GUIDE BEARING AND SPRING THRUST BEARING



KINGSBURY THRUST BEARING AS SUPPLIED TO PENNA WATER & POWER CO. DIAM. 48" LOAD 410,000 LBS. NORMAL SPEED 116 R. P. M.

CONSUMER'S POWER CO., JACKSON, MICHIGAN VIEW SHOWING GOVERNOR SYSTEM

BEARINGS



LOMBARD ACTUATOR TYPE GOVERNOR

with a deep housing in case it is desired to install water cooling coils to remove the heat from the surrounding oil bath.

The bearing surface of the runner is finished with extreme accuracy and is given a high polish. Radial grooves in the rotating bearing surface produce a rapid circulation of oil across the babbitted surface. The babbitt surface upon which the runner revolves is given an accurate tool finish in the factory, and it is not necessary to give this surface any further finish such as hand scraping to the runner or to a surface plate, which is generally done in the case of other types of bearings.

The spring thrust bearing and the upper guide bearing of small vertical generators are usually combined in the same housing. The rotating grooves in the thrust bearing pump the oil up through the guide bearing, making the two bearings self oiling. This combination of the upper guide bearing and thrust bearing effects a considerable economy of space and may be used for loads of about 100,000 lbs. and less. This type bearing can be used with very high unit surface pressures and is particularly effective in starting or stopping.

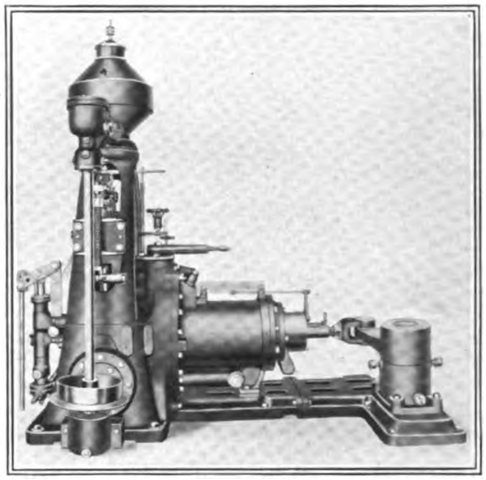
The proper position for the thrust bearing of a vertical unit is on top of the generator, supported by a spider or yoke mounted on the generator frame. This arrangement simplifies the design of the turbine, makes a more compact unit, and avoids the danger of vibration which is always present if the shaft is in compression, particularly if the speed is high.

GOVERNORS

We are prepared to furnish governors of any standard make to suit the requirements of the purchaser, and to connect them properly to the turbine and guarantee satisfactory results. Governor building requires much work and equipment of a special nature, and we believe can be most economically handled in a plant devoted exclusively to this branch of manufacture. The governors for our wheels, however, are incorporated in the turbine contract, and there is no division of responsibility so far as the purchaser is concerned.

The rapid growth in size of units has brought about a corresponding change not only in the size of governors, but also in the arrangement. Standard governors were formerly self-contained; that is, the control and power elements were combined in the governor itself. It was necessary only to connect the centrifugal element to the turbine shaft and the power element to the turbine gate mechanism, and the installation was complete excepting the pumping system.

While this arrangement has to a certain extent survived for use with small units, it is no longer used for large units. In the latter case the centrifugal control mechanism and regulating valves are now combined and localized in an actuator placed in any convenient position near the unit, and the power element or servo-motor is incorporated in the design of the turbine. By separating these elements, each of them may be located in the most advantageous position with respect to the individual function it has to perform. For example, in the case of vertical units, the actuators may be placed on the generator floor and the servo-motors in the wheel pit, directly connected to the gate mechanism.



LOMBARD TYPE T GOVERNOR

Practically all large plants are now equipped with central pressure systems. The pumps are generally of the rotary type motor-driven with automatic control. Each unit has its own accumulator or pressure tank situated close to the governor to eliminate the effect of inertia in the supply pipe, and unless the discharge piping is of liberal size each unit should have a local sump tank from which the oil or water returns by gravity to the central sump supplying the pumps. All governor systems are now arranged to discharge under atmospheric pressure. The vacuum system, at one time commonly used, has been discarded, even in connection with individual pumping systems, because of the tendency to break down the oil.

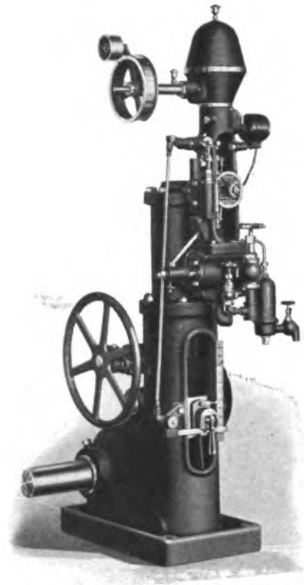
Small units generally have independent or separate pumping systems. The rotary pump and sump tank are built in the base of the pressure tank. The pump is either belt or motor driven. For medium sized governors the several pumping units in a plant may be interconnected by piping to form a more flexible arrangement and to preclude the shutting down of a generating unit for repairing its pump.

Self contained governors built up to 60,000 ft. pounds capacity are equipped with mechanical hand control independent of the servo-motor. This is scarcely feasible with the actuator type governors. They are equipped with hand control of the operating pressure and a hand oil pump is provided for the initial starting up of the plant in case outside power is not available for operating the motor driven pumps. This hand control is independent of the centrifugal speed element, and is also independent of the regulating valves of the governor. In addition to local hand control, all governors are now equipped with manual control from the switchboard.

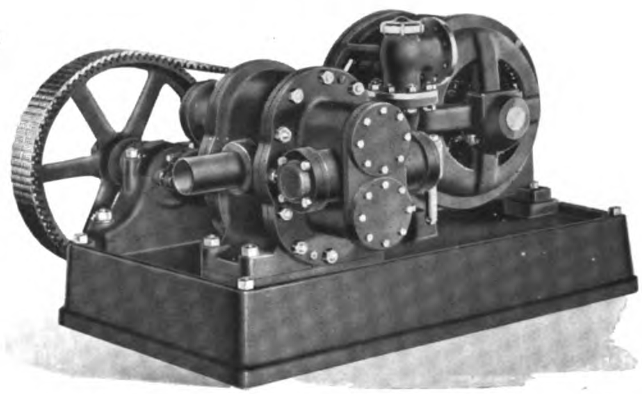
A belt drive for the flyballs direct from the turbine shaft has proven superior to a gear drive and is now recommended for all vertical units. An automatic belt tightener should be provided preferably at the wall of the pit liner.

WOODWARD ACTUATOR TYPE GOVERNOR

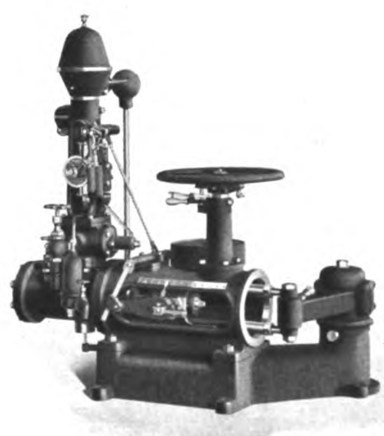
WELLMAN-SEAVER-MORGAN GAUGE STAND WITH AIR BRAKE CONTROL



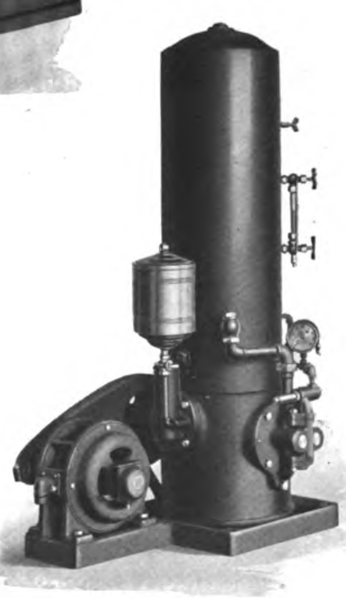
WOODWARD TYPE L R GOVERNOR



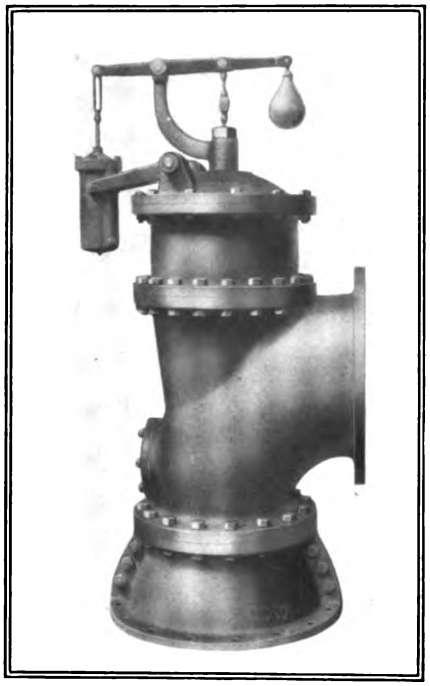
WOODWARD MOTOR DRIVEN ROTARY PUMP



WOODWARD TYPE H R GOVERNOR



WOODWARD ROTARY PUMPING UNIT FOR GOVERNOR



STANDARD GOVERNOR-OPERATED PRESSURE REGULATOR

GOVERNORS

The degree of speed regulation depends upon the rapidity of governor action, fly wheel effect of rotating parts, and the inertia effects in the penstock, wheel casing and draft tube. The inertia effect is a function of the speed of governor action, and is usually found to be the limiting factor. The governor stroke must be slow enough to avoid excessive rise of pressure in the penstock and wheel casing. Few conditions will warrant a governor stroke quicker than 2 seconds.

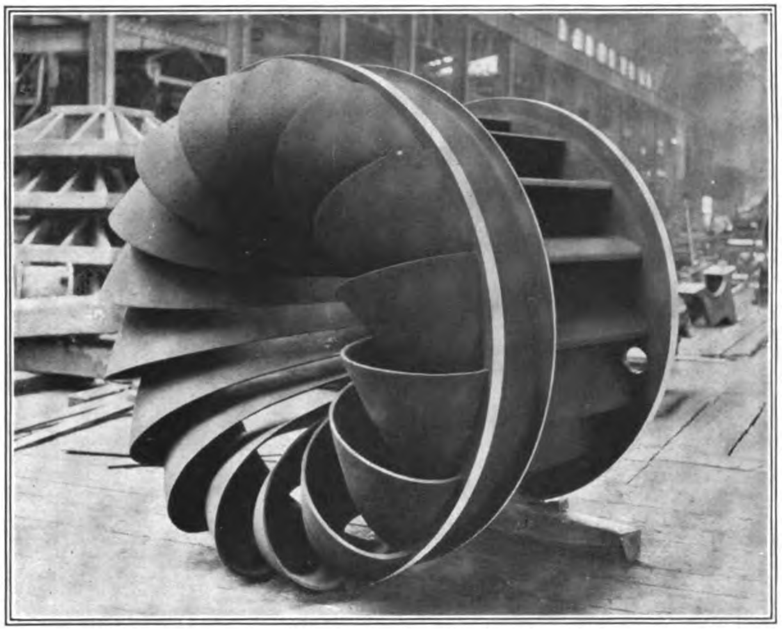
PRESSURE REGULATORS

Although the two are intimately related, pressure regulation is a problem apart from speed regulation, so far as the governor is concerned, and must be provided for in the design of other parts of the plant. If the conduit is long, either enough fly wheel effect must be provided to permit slow governor action, or a surge tank must be used. If the surge tank cannot be located close to the power house, pressure regulators must also be provided. Some conditions may require the use of all these devices.

Pressure regulators in general are of two types; one, synchronous governor-operated, and the other pressure-operated. The latter is more properly termed a relief valve, inasmuch as its function is to relieve a rise of pressure and thus prevent a further increase, whereas the former operates to prevent a rise of pressure rather than to relieve it after it has occurred. The pressure-operated type does not become operative until the pressure in the penstock or turbine casing has risen above normal, whereas the governor-operated regulator goes into action simultaneously with the turbine gates. When the gates commence to close in response to the action of the governor under a sudden rejection of load, the pressure regulator begins to open. This action continues until the gates stop moving. The regulator is designed to be a complementary function of the turbine gates, the water rejected by the turbine as the gates close being discharged through the regulator. Thus the penstock velocity instead of being suddenly checked, resulting in water hammer, remains practically unchanged until the gate action ceases. The regulator then automatically closes itself very slowly, reducing the penstock velocity without appreciable rise of pressure. Frequently conditions demand that a constant quantity of water be passed thru the power house regardless of the load on the turbines. For example, when the power house is installed below a regulating reservoir, on an aqueduct supplying water to a municipality, or on an irrigation system. Our governor operated pressure regulators are particularly adaptable for such requirements. They can be readily adjusted so that any desired amount of water up to the full discharge will at all times be passing either thru the turbine or thru the pressure regulator or both.

In order to obtain ideal results, the maximum capacity of the regulator should be equal to the full-load discharge of the turbine less the discharge required to run at synchronous speed without load. Ordinarily some sacrifice is made to reduce the size of the regula-

PRESSURE REGULATORS



RUNNER OF 6 000 HP TURBINES BUILT FOR THE SANITARY DISTRICT OF CHICAGO. THESE WHEELS EARNED THE LARGEST BONUS FOR EFFICIENCY ON RECORD

tors. They are seldom installed in excess of 75% of the maximum turbine discharge, and in many cases not more than 40% or 50% is provided. In such cases, of course, some pressure rise occurs in the penstock. The size of regulator depends largely upon the velocity in the penstock and upon the length of penstock between the turbine and the forebay, or between the turbine and the surge tank, if one is used.

The standard W-S-M governor-operated pressure regulator is mechanically connected to the gate mechanism of the turbine, but the power required to operate it is supplied by the pressure in the penstock. No load is imposed upon the governor nor any pressure drawn from the governor system. The connection to the turbine gate mechanism simply operates the pilot valve of the regulator which controls its action.

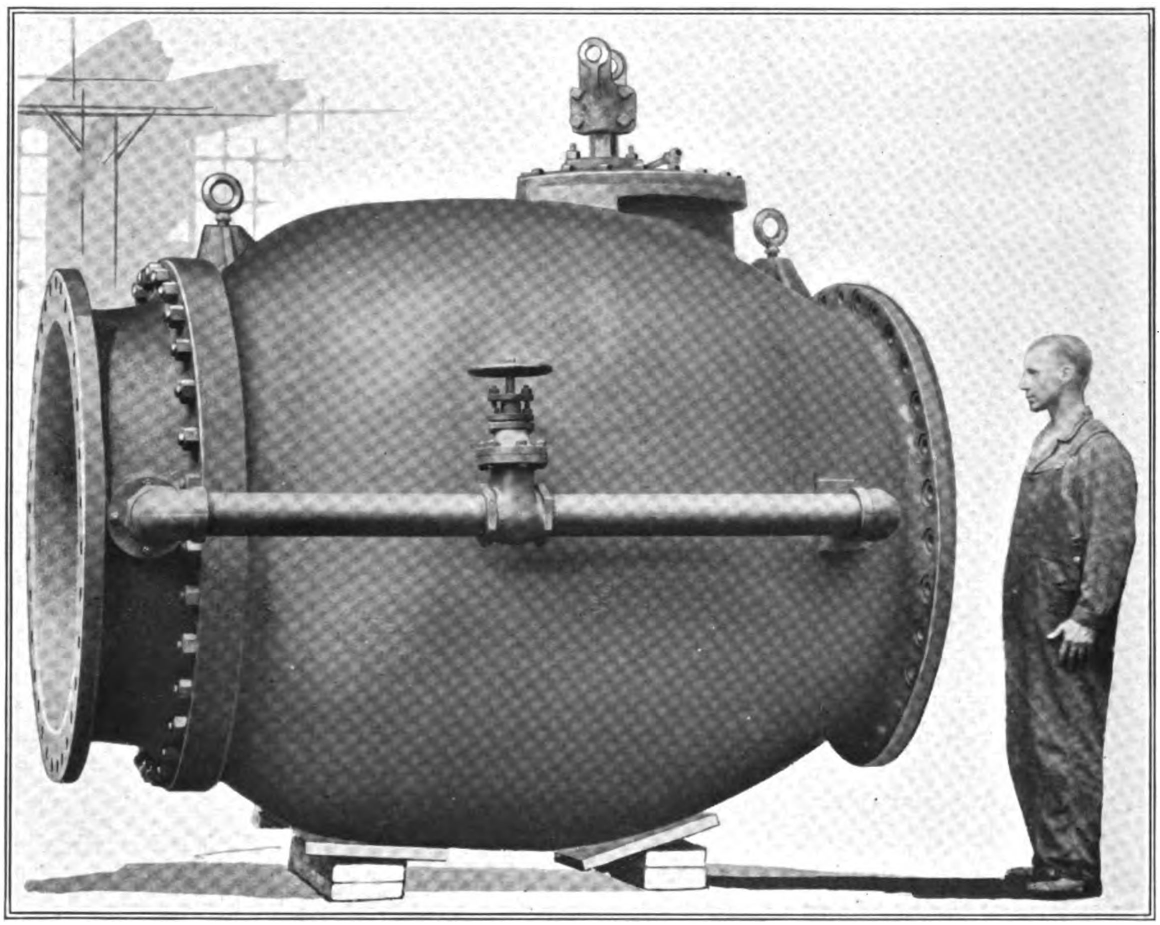
This regulator may also be used as a synchronous by-pass if desired. The change can be made almost instantly and without interrupting the operation of the regulator. The automatic self-closing feature is then eliminated and the regulator remains open, wasting water, whenever the turbine is carrying less than the maximum load for which the regulator is adjusted. The regulator is fully closed only when the turbine is carrying maximum load, and is wide open only when the turbine is running without load. The adjustment is such that the discharge of the regulator plus that of the turbine is always approximately constant and equal to the maximum discharge of the turbine. In this manner the penstock velocity remains constant, independent of the load, and therefore there are no appreciable fluctuations of pressure. Such a regulator performs the same function as a surge tank, although it, of course, wastes water, whereas the surge tank does not. The by-pass feature can be used to advantage only in exceptional cases such as in plants where the load is ordinarily steady but subject to large fluctuations during short periods of regular occurrence. This condition can then be anticipated by changing the regulators from single to double-acting during such periods, thereby materially improving the speed regulation at a comparatively small expense of water.

The rapidity of the governor action is the controlling factor in the operation of the pressure regulator. The pressure regulator is adjusted so that for very gradual load changes which would only cause very slight pressure rises, it will remain closed in order to save water.

The governor and pressure-operated types are essentially the same in design, excepting the control mechanism. All sliding contacts exposed to the water are bronze faced and all parts subject to wear are renewable. Regulators are usually attached directly to the turbine casing and discharge into the tail race. The discharge should not be connected to the draft tube.

They are sometimes installed in duplicate, either two governor-operated or one governor-operated and one pressure operated, each regulator having one-half of the total capacity required. The turbine casing and penstock are then designed to be safe against the rise of pressure which would result should one of the regulators for any reason fail to operate.

THE W-S-M BALANCED PLUNGER HYDRAULIC VALVE



SIDE VIEW OF 48" MECHANICALLY OPERATED BALANCED PLUNGER VALVE FOR UNITED STATES RECLAMATION SERVICE

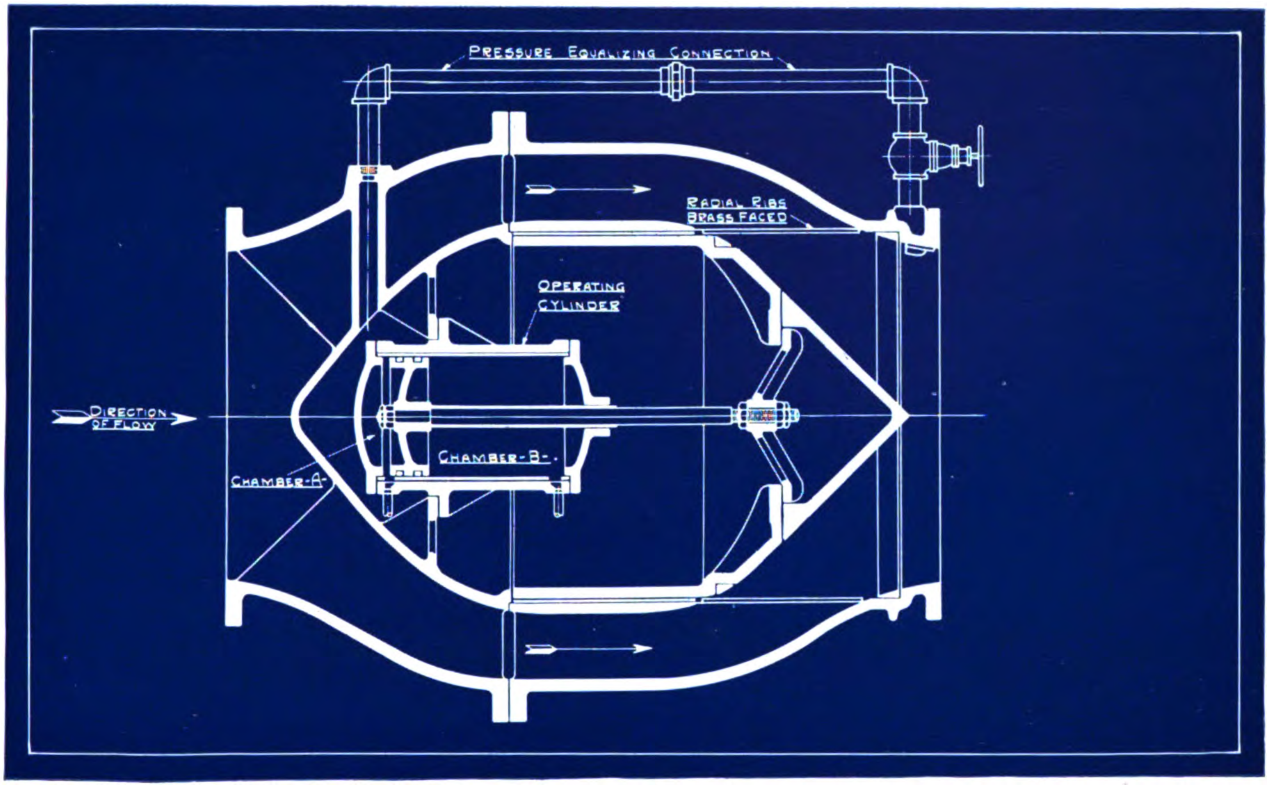


FIG. 12. STANDARD CAST-BODY VALVE, VALVE OPEN

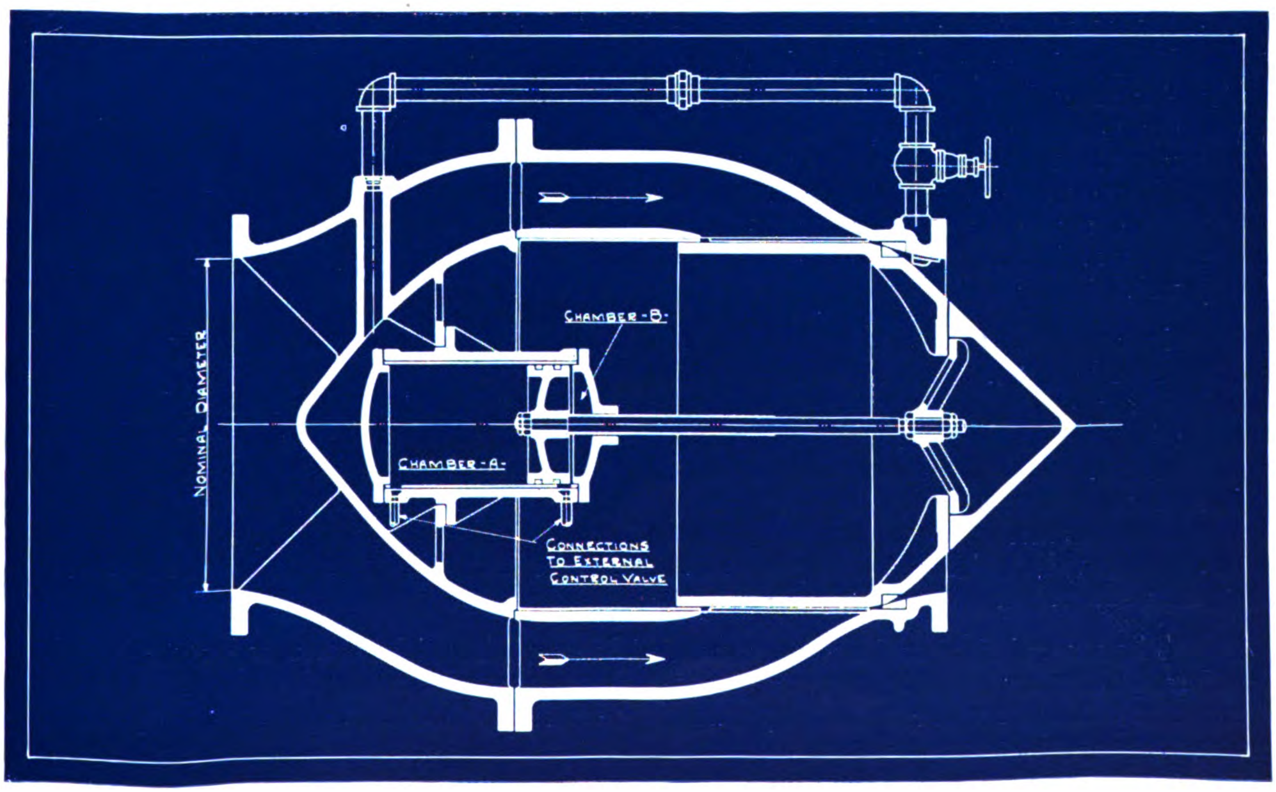


FIG. 13. STANDARD CAST-BODY VALVE, VALVE CLOSED

THE W-S-M BALANCED PLUNGER HYDRAULIC VALVE

PATENTS PENDING

PRACTICALLY the same principles of valve operation are being used in hydraulics today as were used by the ancient Egyptians. The early method of regulating the flow of water was by the raising and lowering of a sluice gate, or the swinging of a pivoted gate. From these crude proto-types have been developed the modern gate and butterfly valves which depart but slightly in principle of operation from the ancient valves. The deficiency in this principle has been recognized by the development of the plunger or needle type valve. This type shows a marked improvement in valve design, although the manifest weaknesses of most of the plunger valves, being manufactured today, make them scarcely preferable to gate or butterfly valves. In fact, most valves now in operation are dangerous, not only to the pipe line or penstock itself, but to the entire plant.

The primary purpose of a valve is to throttle or regulate the flow of water or other fluids. Valves have always accomplished the basic function of shutting off the flow of water, but present day conditions demand that a valve be more than an apparatus to merely do this. An entirely successful valve must be one that may be opened or closed quickly with a minimum of effort without producing a dangerous pressure rise under extreme conditions with water flowing through the valve. It should be of a design free from questionable strains and distortions, and together with its operating mechanism, so simple and controllable that it is safe in the hands of an inexperienced operator. How many valves used today will meet these specifications?

Gate valves practically without exception are inefficient due to the inherent faulty principles of design. Except in the smaller sizes they can be operated only with great difficulty and under high pressures scarcely at all without by-passing, or equalizing pressure on both sides of the gate or disc. Even where it is possible to operate them without by-passing, on account of the enormous load on the gate, and the deflection due to the unbalanced condition, the bearing pressure on the guides is exceedingly high resulting in rapid wear and scoring of the sliding surfaces and seats which, in course of time, means a leaky valve.

Butterfly valves present much the same weaknesses. Unless conditions permit the valve to be by-passed, the movement of the disc in flowing water particularly under high heads is a precarious operation. In the hands of a careless operator the pressure rise caused by the sudden slamming of the disc to its seat is exceedingly dangerous. It is practically impossible to accurately anticipate in the design the strains produced in the operating mechanism and disc. Furthermore, if the disc is created sturdy enough to overcome deflections it assumes a shape that seriously interferes with the flow of water through the valve. The butterfly valve is not tight and it is difficult to close it hard on its seat without jamming.

The wasted time and energy expended in operating either gate or butterfly valves condemns their use in an emergency. Nor can either type be maintained partially opened for use as a control valve, without producing excessive vibration and improper jet conditions, resulting in a loss of head.

The best designed plunger, or needle type valves now in use are likewise at fault in principle of operation. Most of these are operated by creating an unbalanced condition of forces acting directly upon the plunger itself. This condition combined with the uncontrolled fluctuating pressures on the nose of the plunger produce the eccentric actions so common to these valves, particularly under high heads. Such types also are unsatisfactory when it is necessary to operate them in flowing water in an emergency.

The problem of selecting thoroughly reliable valves has long perplexed hydraulic engineers, but they have been handicapped in their selection by the non-existence of such valves. There is the familiar example of a hydro-electric installation protected by head gates for shutting off the water, and valves placed in the penstock as an emergency provision. Existing valves so placed which should operate surely, quickly, and safely in an emergency, will not do so and are therefore no more effectual than the slow closing head gates.

The weaknesses of such valves have been recognized, and analyzed by the engineers of The Wellman-Seaver-Morgan Company, and after exhaustive tests the design of the W-S-M Balanced Plunger Valve perfected.

THE W-S-M BALANCED PLUNGER HYDRAULIC VALVE

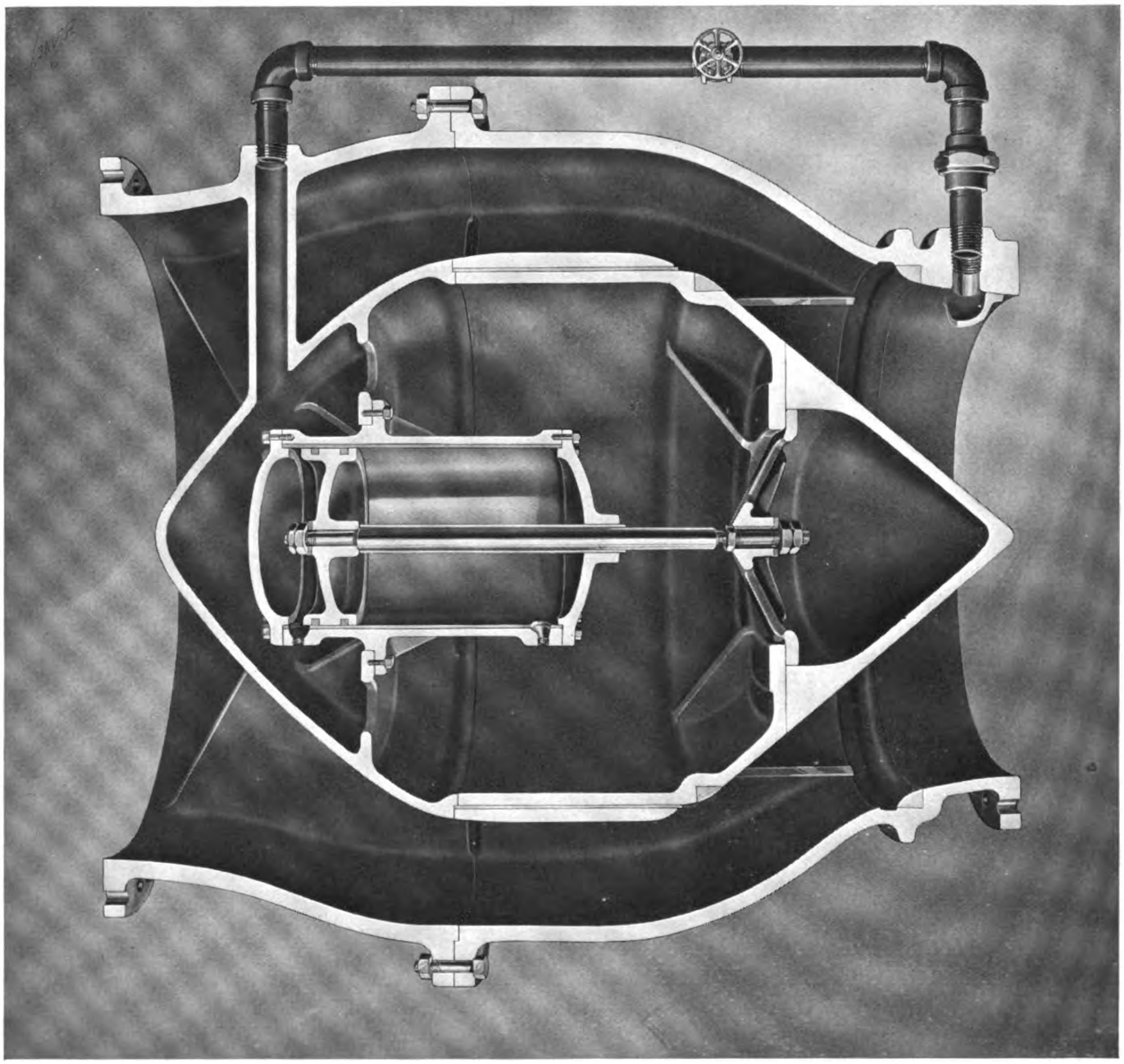
THE W-S-M Balanced Plunger Valve consists essentially of a body of circular section. This contains an internal cylinder closed at one end forming a central chamber in which there is a sliding plunger, connected to an operating cylinder on the conical head of the internal cylinder, by means of a connecting rod. There is a pipe connection leading from the central chamber to the neck of the valve which maintains the plunger in a balanced condition at all times. On the mechanically operated type gearing supplants the operating cylinder as a means of moving the plunger.

The forces operating the plunger of this valve are entirely independent of the variable forces acting on its nose. An external control valve is connected to the operating cylinder by means of suitable piping. Admitting pipe line pressure to chamber "A" of the operating cylinder and exhausting chamber "B" of the operating cylinder to atmosphere, will close the valve, and a reversal of this operation will open it. It is obvious that since the plunger is in a balanced condition at all times that only sufficient force to overcome the friction of the plunger sliding on the bronze liners of the body, will be required to operate the valve although the operating cylinder is capable of delivering many times that force.

FEATURES OF THE W-S-M BALANCED PLUNGER VALVE

Reliability: The plunger may be said to be lying in dead water due to the equalizing pipe connection leading from the central chamber to the neck of the valve, which maintains at all times practically equal forces on both sides of the nose of the plunger. This is a detail, the importance of which cannot be emphasized too strongly. Due to this the valve is completely under control at all times.

This Valve Will Not Slam Shut: The rapid termination of the closing stroke, or the slamming shut of most needle type valves, with the attendant dangerous water hammer, is undoubtedly the greatest disadvantage of this type of valve, as they are usually built. Water hammer is caused by the sudden stoppage of a moving column of water. It can be avoided only by slowly throttling the flow, particularly at the very end. The ideal valve is therefore one which will shut off about 75% of the flow rapidly, with the remaining 25% at a decreasing rate of speed terminating in an almost imperceptible motion. To illustrate let us consider the closing of a typical needle type valve. As the plunger moves toward its position to close the valve it restricts the water passage in the discharge opening,



SECTION SHOWING GENERAL DESIGN AND CONSTRUCTION OF HYDRAULICALLY OPERATED VALVE

thereby increasing velocity and accordingly decreasing the reactive forces on the nose of the plunger, while the greater opposing force within the plunger continues. As it nears its seat this opening is so restricted that not enough water passes to fill the penstock below the valve, causing a break in the water column, and a vacuum is formed in the neck of the valve which draws the plunger to its seat with a slam causing a dangerous pressure rise. This tendency to slam shut in the last fractional part of closing stroke of the plunger, so inherent in previous designs of needle valves, has been eliminated in the W-S-M valve by the equalizing connection which transmits all pressure conditions from the neck of the valve to the central chamber, and consequently holds the plunger in equilibrium at all times. It is evident, therefore, to operate this valve that only sufficient force is required to overcome the friction of the plunger sliding in the body of the valve. This force is supplied by the operating cylinder, and is entirely free from the varying conditions acting on the nose of the plunger. Also proper design of the ports in the operating cylinder provides for the **actual cushioning of the plunger at the termination of the closing stroke.** This will create the desirable condition of the plunger traveling the greater part of its stroke very fast, and terminating sufficiently slow to avoid water hammer due to the equalizing connection which maintains the plunger in perfect balance.

The W-S-M Valve Will Not Creep Shut. When the plunger of a needle type valve is in the open position there are varying forces acting on the nose of the plunger, if there is any variation in the velocity of the water passing through the valve. If these are decreasing forces the plunger becomes unbalanced and creeps shut. Such conditions are impossible, however, in the W-S-M Valve for any change in pressure in the neck of the valve acting on the nose of the plunger is transmitted to the central chamber by the equalizing connection, maintaining the plunger in a practically balanced condition and eliminating any possibility of the plunger creeping shut. Also due to the plunger being in perfect balance there is no possibility of the valve suddenly closing when just cracking the valve to slowly fill the pipe line beyond, prior to fully opening it. In fact the control mechanism of our remote control valve is so designed that it is impossible to more than crack the valve until the pipe line is completely filled or in effect by-passed. Thus it is impossible for the operator to suddenly open the valve allowing a rush of water into the empty pipe lines.

The valve may be operated quickly, easily and safely in flowing water regardless of pressure due to the fact that the plunger is completely under control during its entire stroke because of the equalizing connection.

Every engineer who has contemplated the problem of operating valves under high pressures in emergency, where by-passing is impossible, will readily appreciate these advantages which are found only in W-S-M valves, due to their scientific construction.

The control mechanism has been reduced to the simplest form consistent with reliable operation.

Tightness: There is a renewable seat ring on the plunger which engages with a renewable seat ring in the neck of the valve when the plunger is closed. These rings of dissimilar metal are carefully ground together to a perfect fit. Also the plunger or sliding element is self-contained in the valve body, and when a perfect fit is once obtained in the shop it is impossible to throw it out of alignment when assembling in the field.

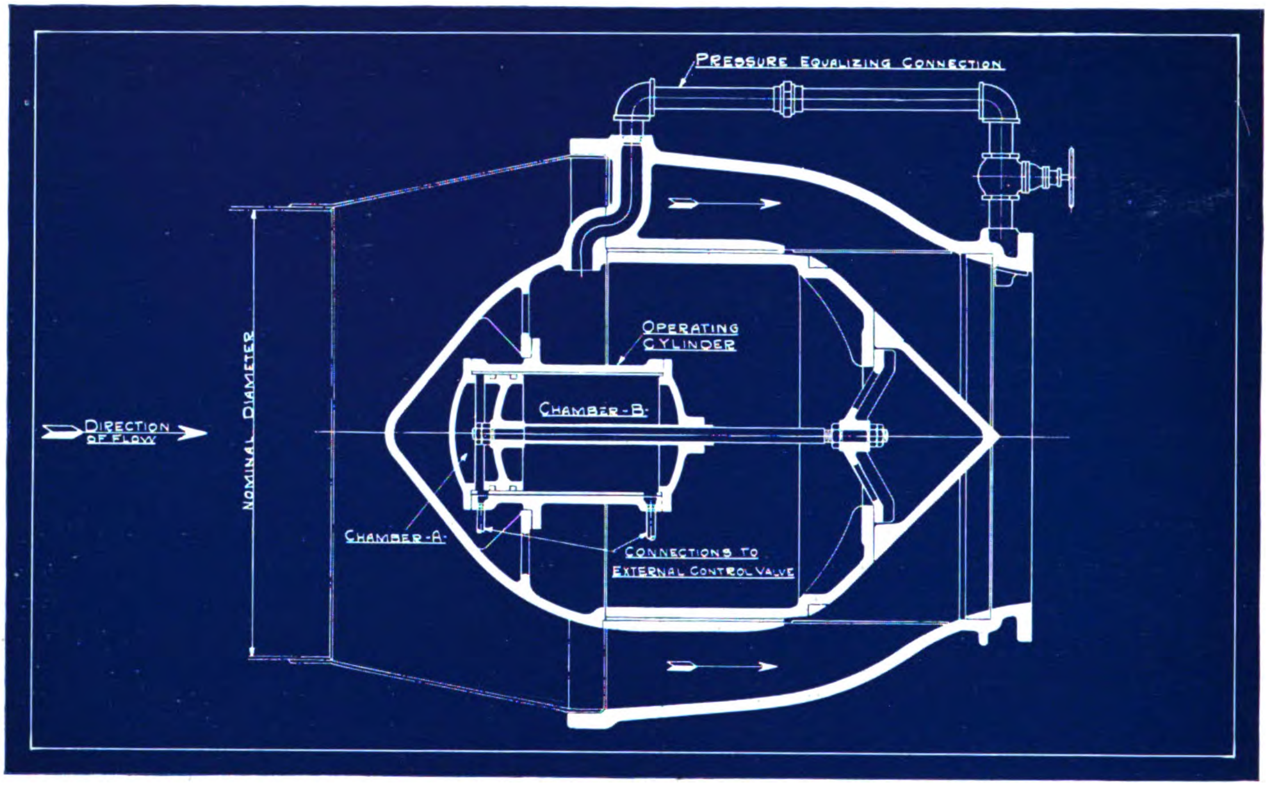


FIG. 14. STANDARD VALVE WITH STEEL PLATE ENTRANCE SECTION

Strength and Durability: The design of the W-S-M valve is entirely free from questionable stresses and strains. All parts are circular in section so that there is no difficulty in accurately determining the maximum stresses. There is an absence of flat surfaces checkered with deep ribs which even with the most careful designing are of unknown strength.

Special attention has been given to durability in the design. All surfaces subject to wear are bronze lined.

The weight of the sliding plunger is distributed over a bearing surface of liberal area and the bearing pressures are therefore exceedingly low. The operating cylinder is also lined with bronze.

Control: A standard valve is provided with hand control but may be equipped for remote electrical control where this is a necessity or an actual convenience. Hand operation is also supplied when remote electrical control is furnished.

All stop valves in the control piping are normally wide open, thus eliminating the wear or wire cutting of the seats which is sure to result under high pressures when such valves are partly open.

There is no possibility of sediment or sand collecting in the operating cylinders. The control valve connections are of ample size and the ports in the operating cylinder are so arranged that the chambers are flushed each time the valve is operated. In case the water in the penstock is exceedingly dirty the valves may be operated by pressure from any available outside source, since the amount of water actually required to operate the valve is small.

For remote electrical control an indicator board is so arranged at the operating stand that the position of the plunger is shown at all times and not merely at the extremes of its stroke as in the average installation.

Water Passages: Particular attention has been given to the design of the water passages of the valve. The passages are so shaped as to conform to the natural flow of the water. There are no pockets, sudden changes of direction, or obstructions to create a loss in head.

Measurement of Flow: In certain types of valves where the inlet end of the valve is larger than the outlet end, the valve may be utilized as a Venturi meter. The proportions are, however, different from those of a Venturi meter and it is necessary that the instruments be especially calibrated. This may be done where there is some independent means of measuring the flow, and after the instruments are calibrated there will be a daily record of the amount of water passing through the valve.

Water Works Valves: The features of the W-S-M balanced plunger valve make it ideal for protection of high pressure water mains. This valve can be positively closed in flowing water sufficiently slow to meet water works demands. Water works Engineers know the difficulty of closing a valve in a bursted main when it is necessary to pinch off the flow with a number of valves in sequence until the valve nearest the break can be finally closed. The property damage from this source runs into many thousands of dollars annually, most of which could be avoided if a comparatively quick closing valve were in use.

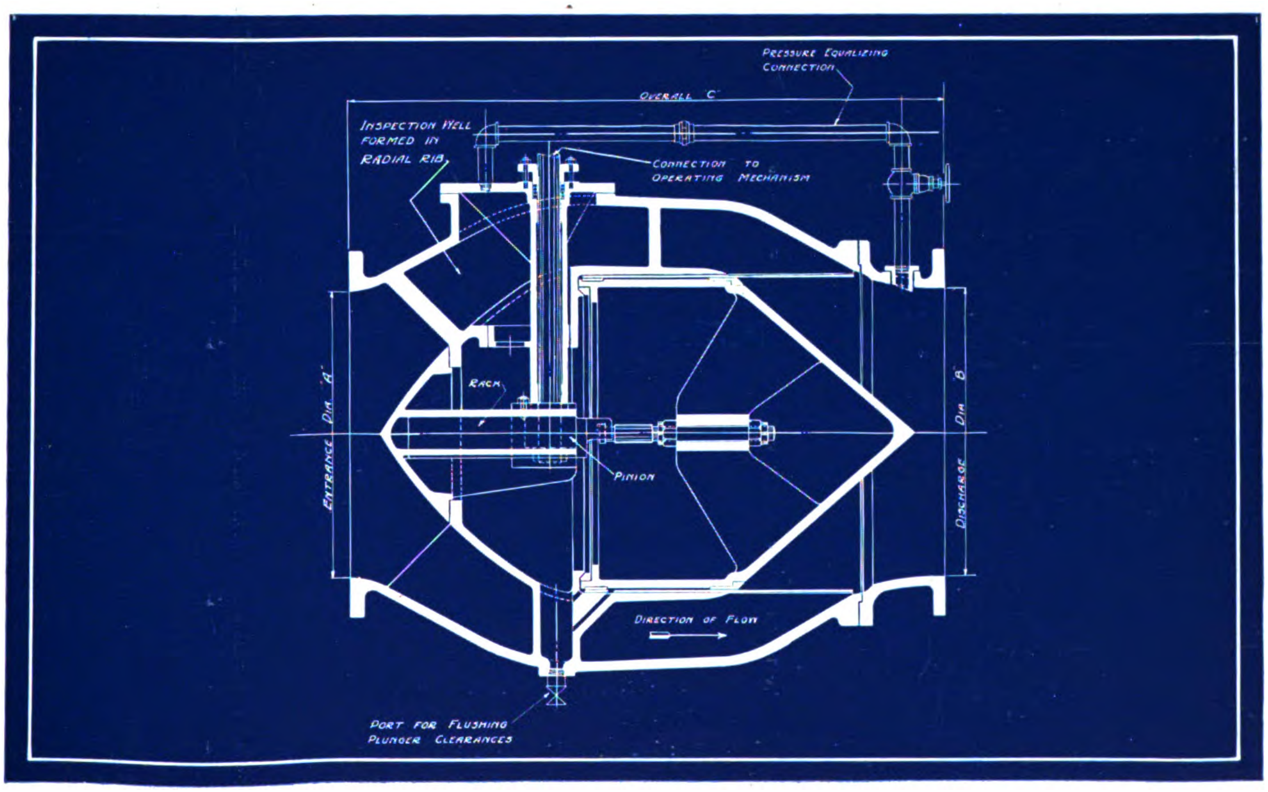


FIG. 15. STANDARD MECHANICALLY OPERATED VALVE

The Wellman-Seaver-Morgan mechanically operated valve is recommended for water works service. This valve may be arranged for remote control and automatic closing if so desired.

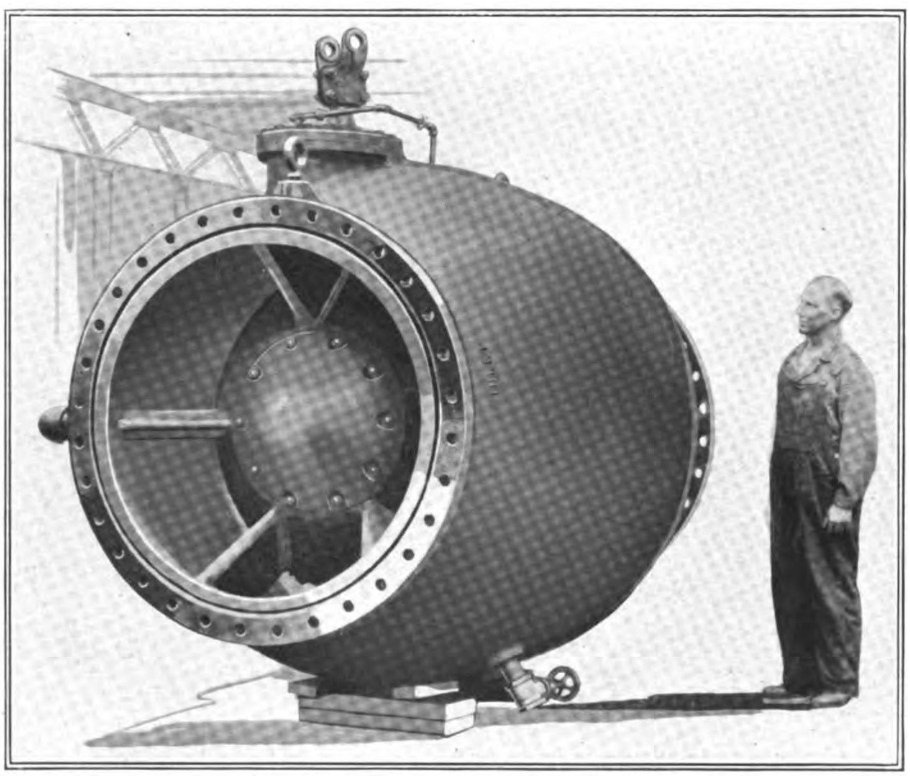
Standard Types: There are three standard types of construction.

No. 1 Cast body type. Standard for hydraulically operated valves, 60″ inlet diameter and under, shown in figures 12 and 13.

No. 2 Partial steel plate body type. 66″ inlet diameter and larger for hydraulic valves shown in figure 14. The rear end of this type is an extension of the pipe line or penstock, and is to be provided by the purchaser inasmuch as these valves are most frequently installed in steel plate penstocks.

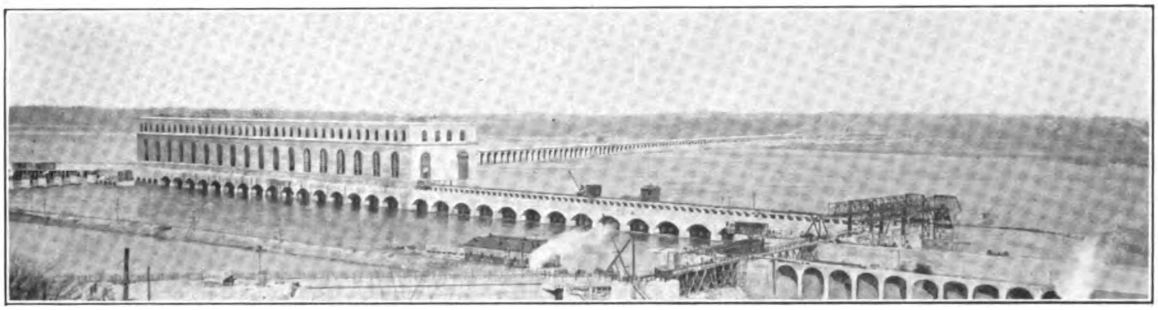
No. 3 Mechanically operated valves which may be either hand or electrically controlled, shown in figure 15. This type is made in all sizes and is designed for use where there is not sufficient head for operating the valve hydraulically.

All types may be installed in a horizontal or vertical position, or at any angle.



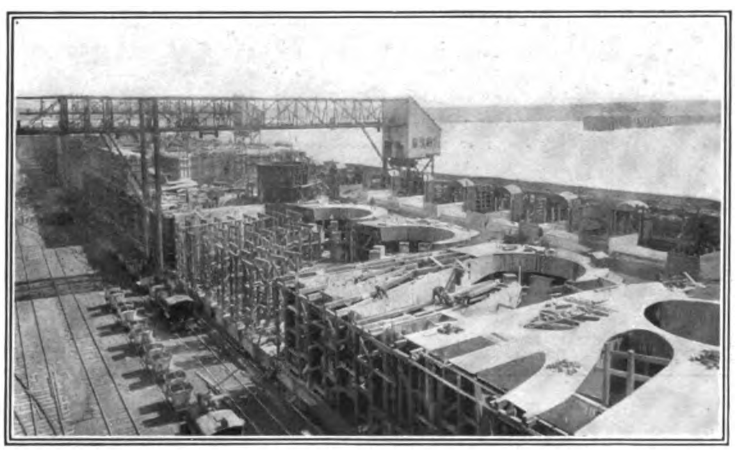
END VIEW OF 48" MECHANICALLY OPERATED BALANCED PLUNGER VALVE FOR UNITED STATES RECLAMATION SERVICE

MISSISSIPPI RIVER POWER COMPANY



THIS mammoth plant, located on the Mississippi River at Keokuk, Iowa, has the distinction of being by far the largest water power development in the world. The power house is at present completed for one-half of the ultimate turbine installation, and the substructure for the other half is partly finished. The complete plant will be about 1800 ft. long, and will contain thirty 10 000 HP main units and four 2200 HP auxiliary alternators or exciter units.

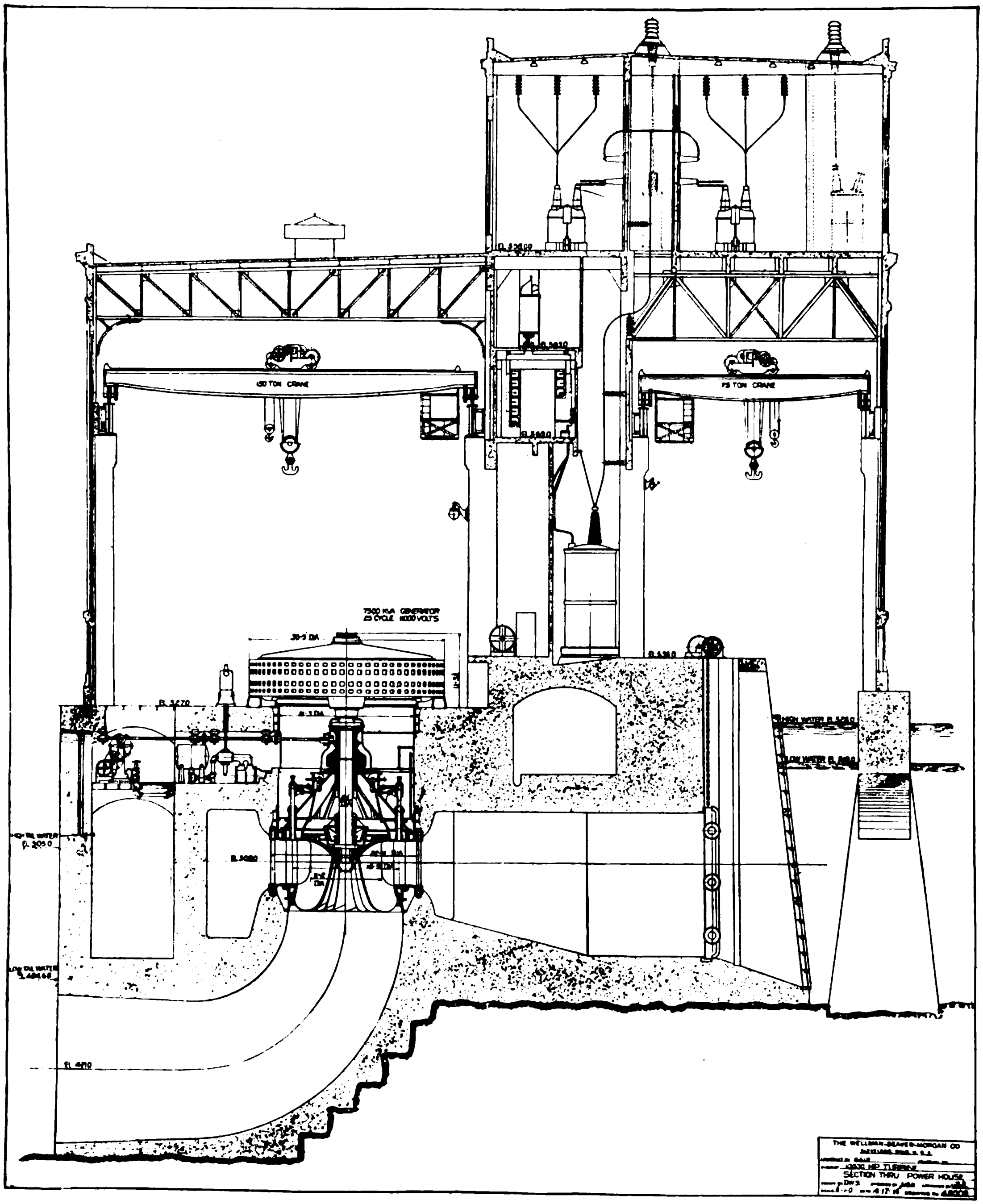
In addition to the power house, the installation comprises a concrete dam 4700 ft. long, extending from the upstream end of the power house to the Illinois shore, a concrete ice fender for the plant, a navigation lock 400 ft. long by 110 ft. wide, and a dry dock. The lock and dry dock were built by the Power Company and deeded to the United States Government for use of the river boats. The lock is as large as any at Panama, except in length.



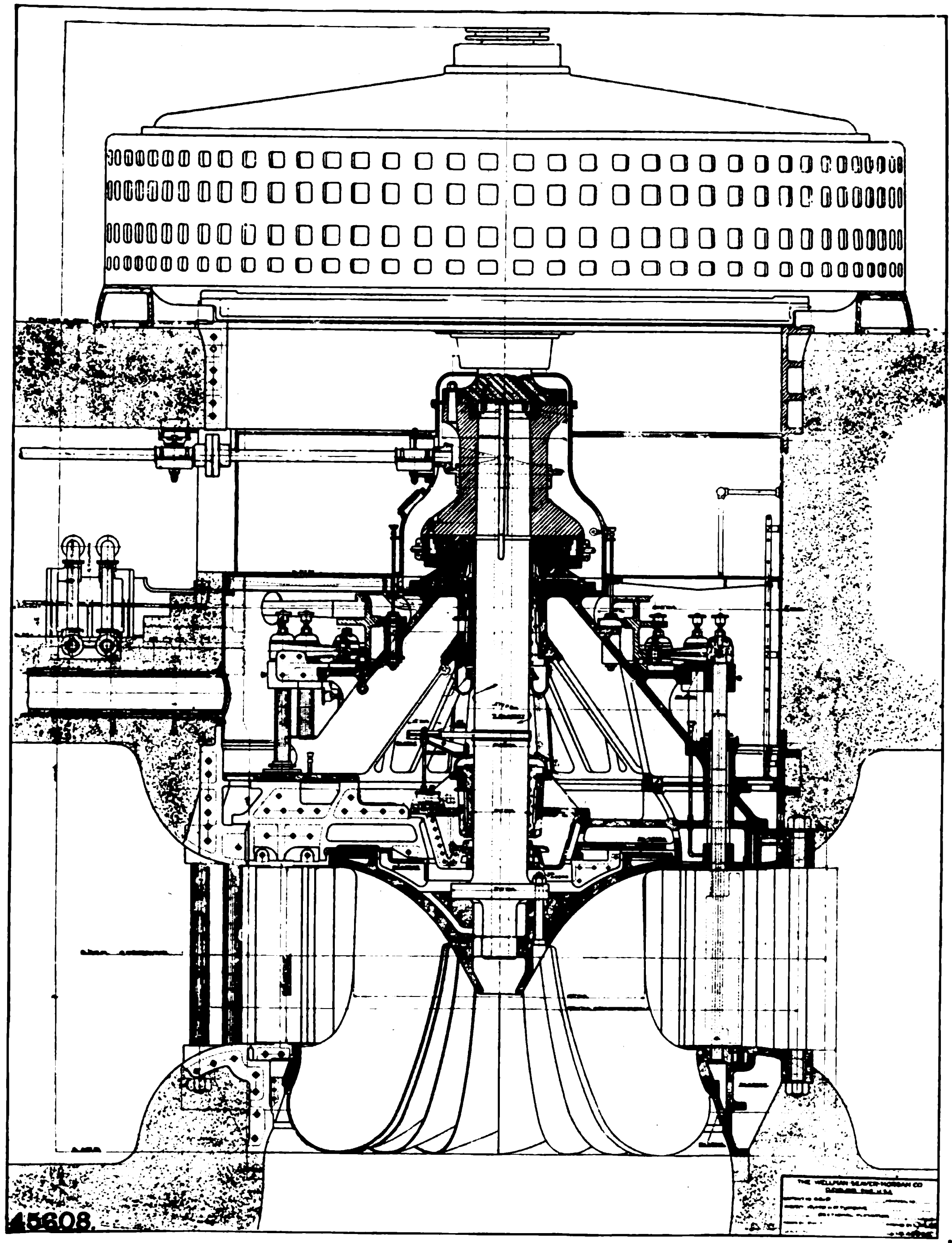
ERECTION OF PIT LINERS AND FORMS FOR CONCRETE SUBSTRUCTURE

The normal head on the turbines is 32 ft. The maximum head is 39 ft., and the minimum 20 ft. The turbines cover this range of head at a constant speed of 57.7 RPM, the output varying from 6000 HP at 20 ft. to 15 000 HP at 39 ft. They have a nominal rating of 10 000 HP at 32 ft. The maximum output at that head is about 11 500 HP. At the time these wheels were constructed they were the largest in existence.

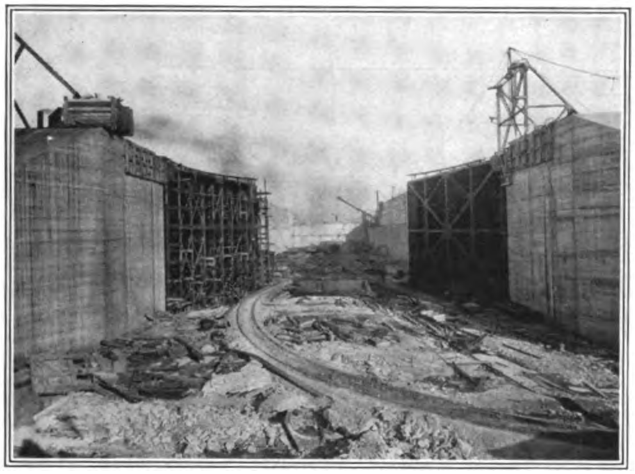
SHOP VIEW OF 10 000 HP TURBINE FOR THE MISSISSIPPI RIVER POWER COMPANY



SECTIONAL ELEVATION OF POWER HOUSE



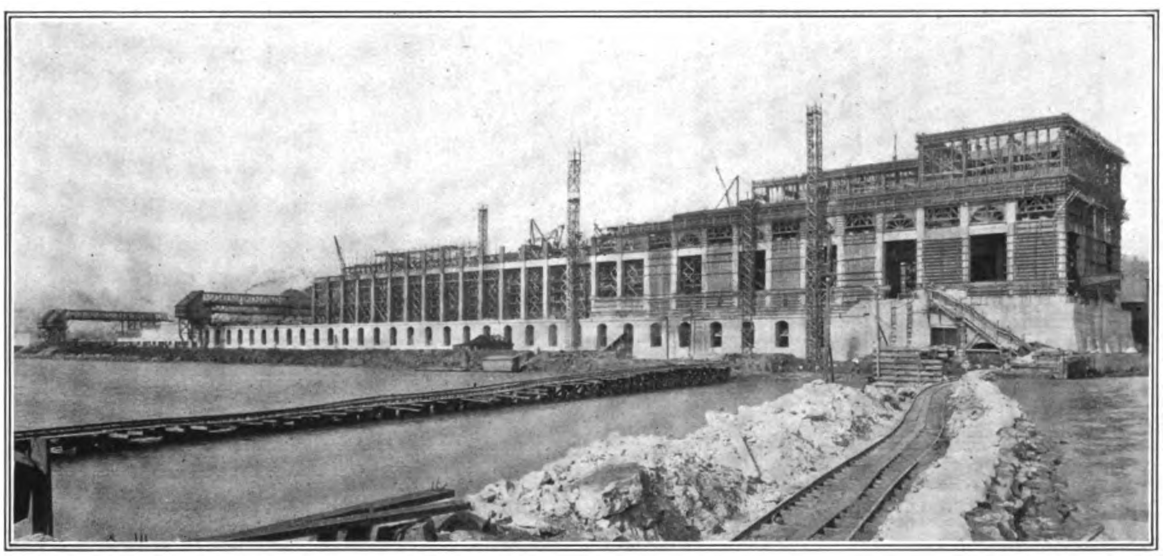
SECTIONAL ELEVATION OF 10 000 HP TURBINE



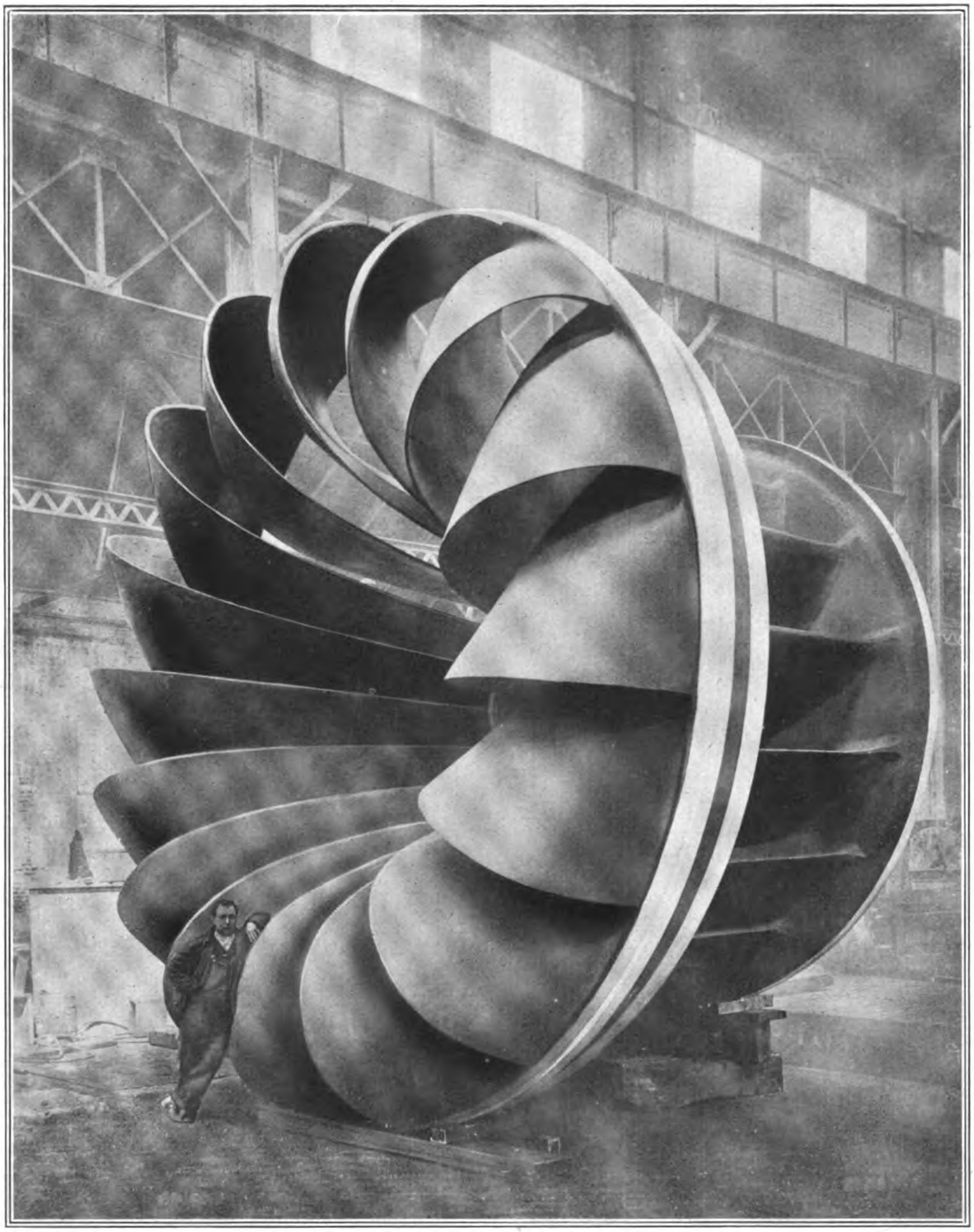
KEOKUK LOCK, LOOKING UP-STREAM

The turbines are of the single runner vertical type with spiral wheel chambers built in the concrete foundations of the power house. Seven of the main units, and the two exciters, were built by The Wellman-Seaver-Morgan Company. The total weight of the turbines is about 1 150 000 lbs. each. The runners are cast iron, in one piece, and weigh about 130 000 pounds. They are bolted to a flange on the end of the turbine shaft. The shaft is hollow, the outside diameter being 25″ and the inside diameter 8″. The weight of the rotating parts of the turbine and generator, amounting to about 450 000 pounds, is carried on a thrust bearing situated on top of the turbine, and below the generator. Part of the units are equipped with Kingsbury thrust bearings, and part with combination oil pressure and roller bearings.

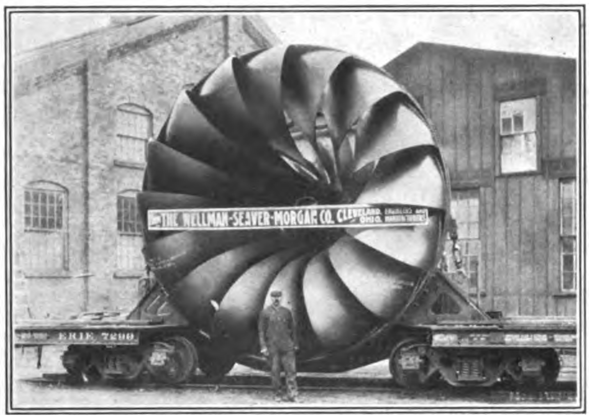
The foundation rings, which form the throat openings to the turbine gates, are of cast iron spaced by forged steel separators. The top of the draft tube has a cast iron collar to prevent erosion of the concrete. This collar is provided with a shoulder to support the runner when disconnected from the shaft.



POWER HOUSE DURING ERECTION OF THE SUPERSTRUCTURE

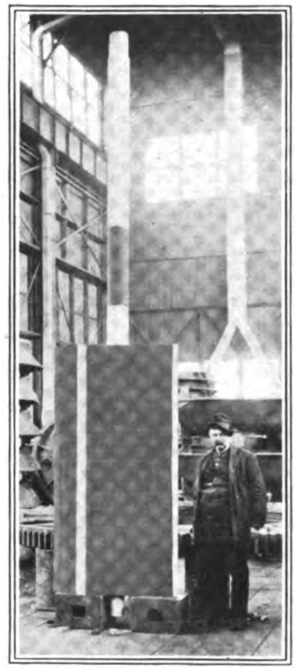


RUNNER FOR 10 000 HP TURBINES OF THE MISSISSIPPI RIVER POWER CO.
THE LARGEST RUNNER EVER BUILT IN ONE PIECE. WEIGHT 130 000 POUNDS



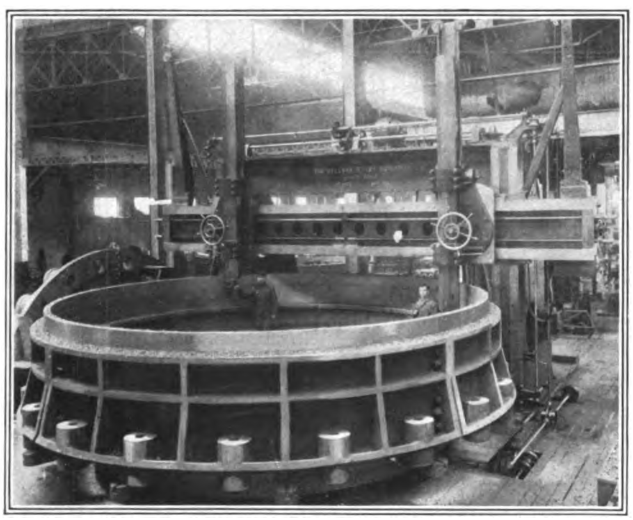
RUNNER LOADED FOR SHIPMENT ON SPECIALLY DESIGNED CAR

The upper foundation ring supports the crown plate of the turbine, upon which rests the conical thrust bearing support. In this manner the entire weight on the thrust bearing is transmitted to the foundation of the power house without passing through the substructure. The circular pit below the generator has a plate steel pit liner forming a continuous water-proof lining extending from the cast steel floor ring to the upper foundation ring. The pit liner has three entrances from galleries in the substructure below the generator floor.



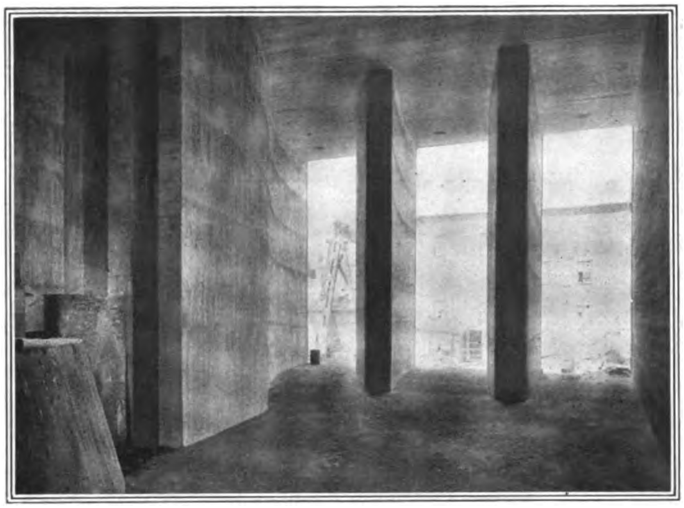
CAST STEEL WICKET GATE FOR KEOKUK TURBINES WITH REMOVABLE FORGED STEEL STEM

The gates are of cast steel with removable forged steel stems. The gate-stems are extended through the thrust bearing support to the level of the lower operating deck, where they are connected by links and levers to a massive cast steel operating ring. The latter is in turn connected at diametrically opposite points to two regulating cylinders.



FOUNDATION RING ON 30 FT. BORING MILL

Extraordinary precautions have been taken to eliminate friction and wear from the gate mechanism. The gates are suspended on ball bearings, with a small working clearance between the curb and crown plates. The weight of the operating ring is carried on ball bearings, and it is guided circumferentially by adjustable rollers. Both gate-stem bearings and all pin connections throughout the entire gate mechanism are lubricated with grease.



WHEEL CHAMBER LOOKING TOWARD INTAKE

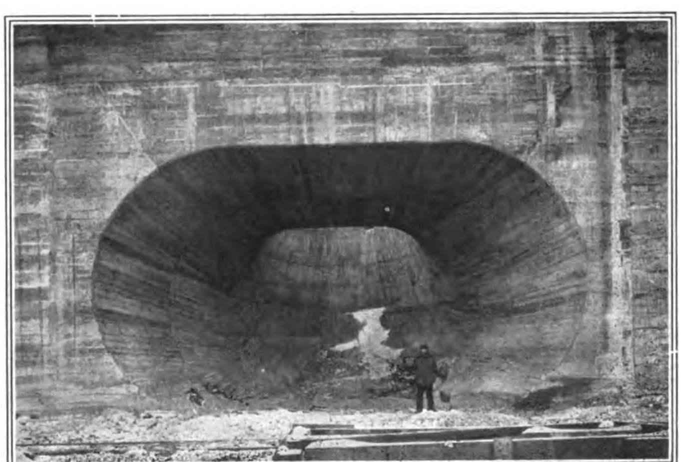
All of the units are controlled by Lombard governors of special design, located on the generator floor. These governors have a capacity of 250 000 ft. pounds each. They work with oil at 200 pounds pressure, and are equipped with all customary devices for local and distant control. In addition, they have a novel gate limiting device for automatically preventing overgateage. On account of the wide variation of head, there is a corresponding wide variation in the maximum allowable gate openings of the turbines.

Each unit has a separate motor-driven triplex pressure pump and accumulator tank. The pumps have automatic starting and stopping switches controlled by the pressure in the accumulators. Each unit has also a belt-driven triplex pump supplying oil at 225 pounds pressure to the oil-pressure thrust bearings. The pressure lines for the thrust bearings are inter-connected between units, and two large motor-driven central system pumps with automatic pressure-controlled starting switches are provided as an additional safeguard against failure of the oil supply. The Kingsbury bearings, and all of the guide bearings are lubricated by gravity feed.

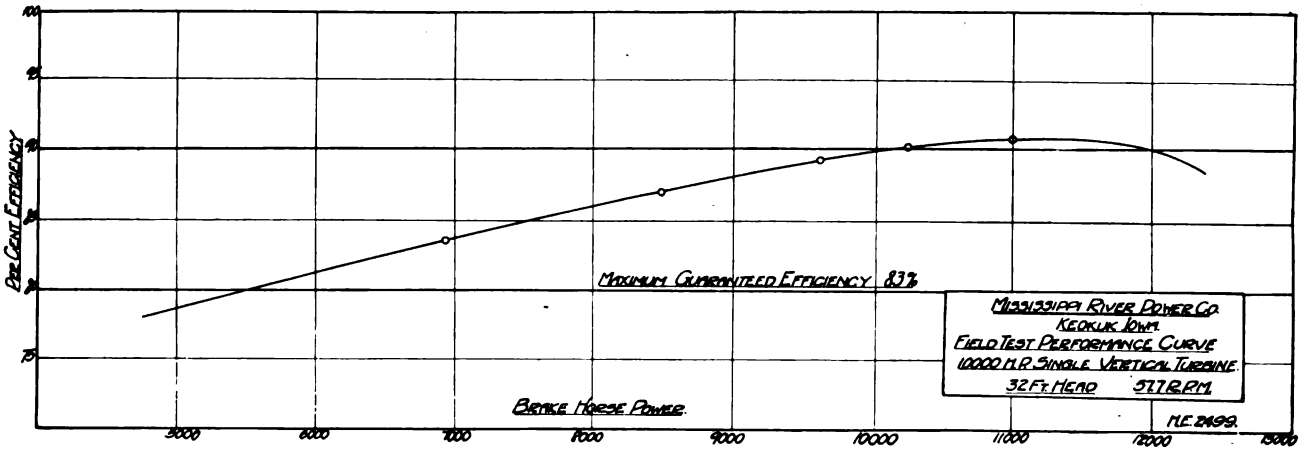
The main generators are 3 phase, 25 cycle, 9 000 K. V. A. 11 000 volt alternators. They are 31 ft. 5 in. outside diameter and 11 ft. 3 in. high at the center. The auxiliary units are 3 phase, 25 cycle, 2 000 K. V. A., 460 volt alternators, operating at 125 RPM, with direct connected exciters. Each main unit is excited by an individual generator set, current for driving the motors being supplied by the auxiliary alternators.

Current is transmitted to St. Louis,. 144 miles distant, at 110 000 volts; to Alton, at 66 000 volts; to Hannibal and Quincy, at 33 000 volts; and to Burlington, at 11 000 volts.

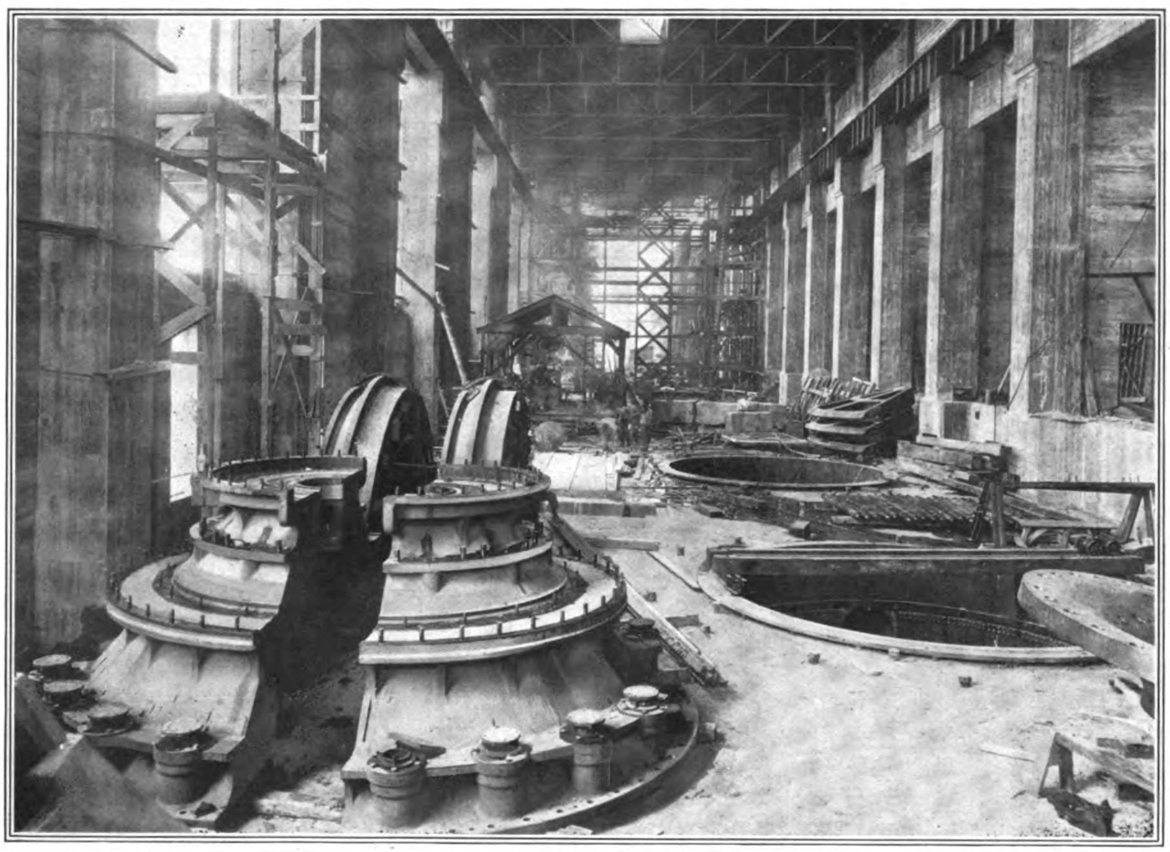
The dam, power house substructure, and all of the hydraulic features of the plant were designed and constructed under the supervision of Hugh L. Cooper, Chief Engineer. The electrical features and the superstructure of the power house were designed and constructed under the supervision of the Stone & Webster Engineering Corporation, of Boston.



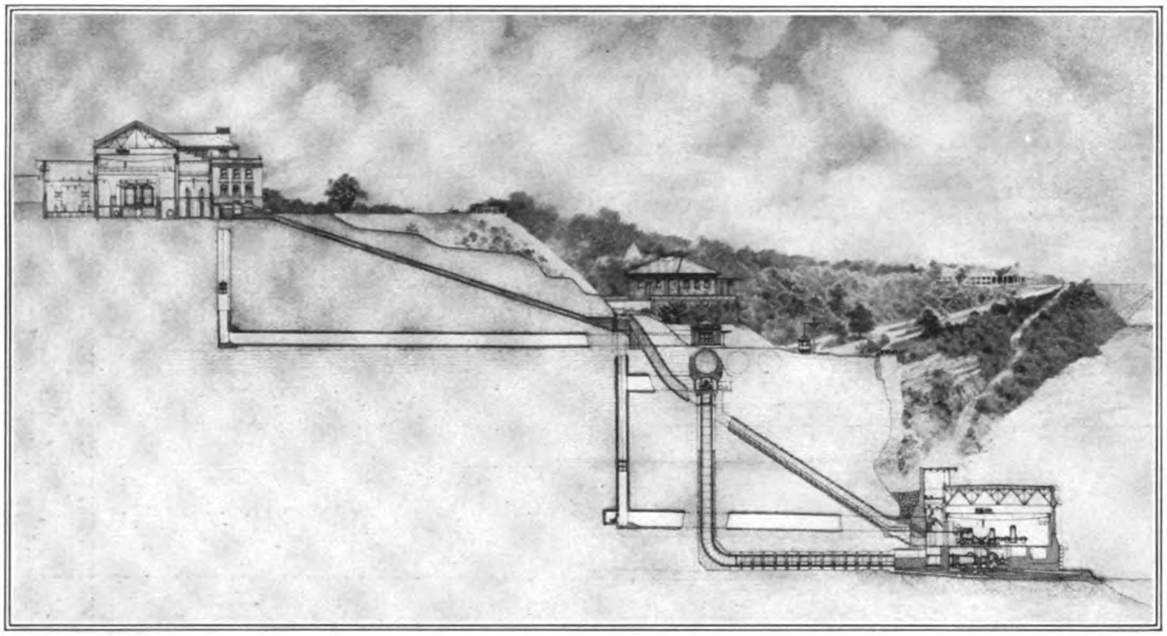
LOWER END OF DRAFT TUBE



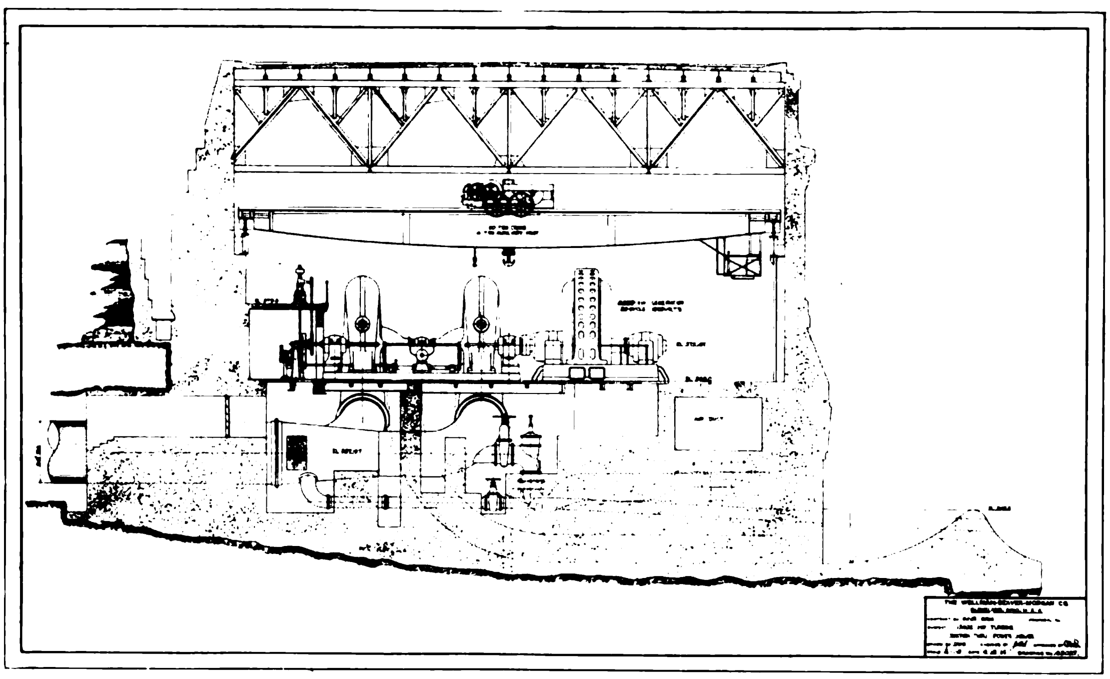
FIELD TEST EFFICIENCY



INTERIOR OF POWER HOUSE DURING ERECTION OF TURBINES

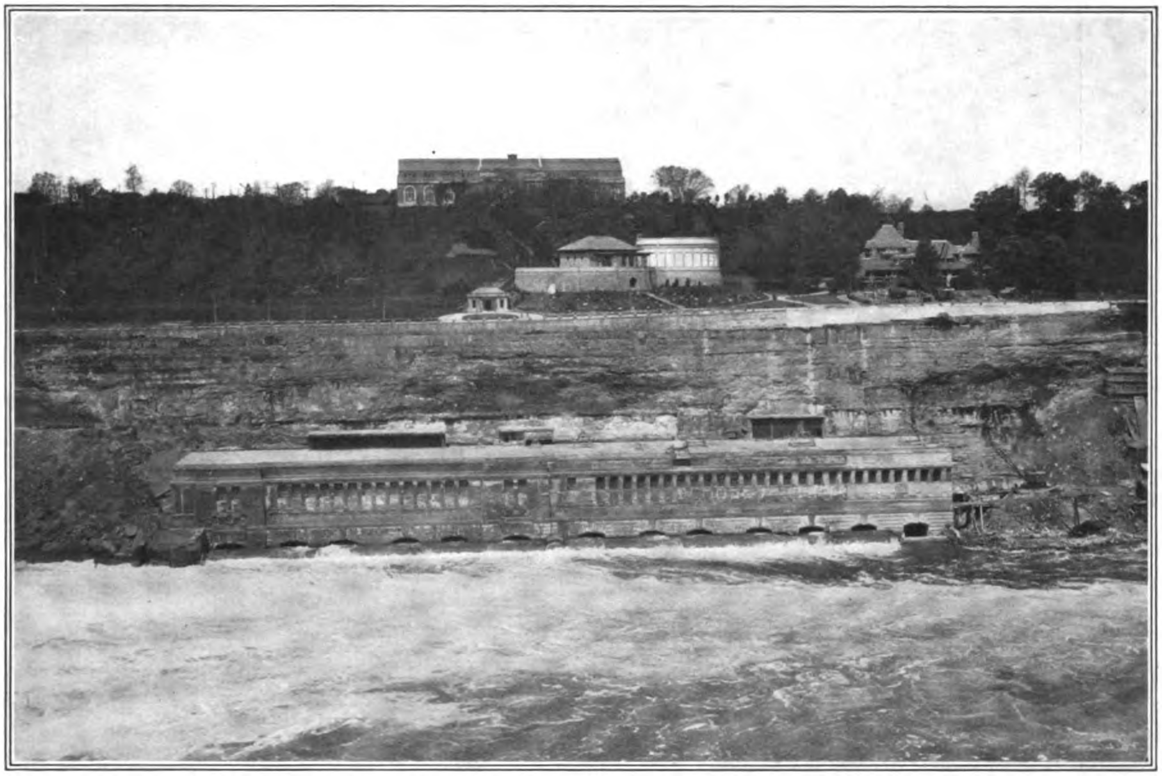


SECTIONAL VIEW THROUGH POWER HOUSE AND DISTRIBUTING STATION



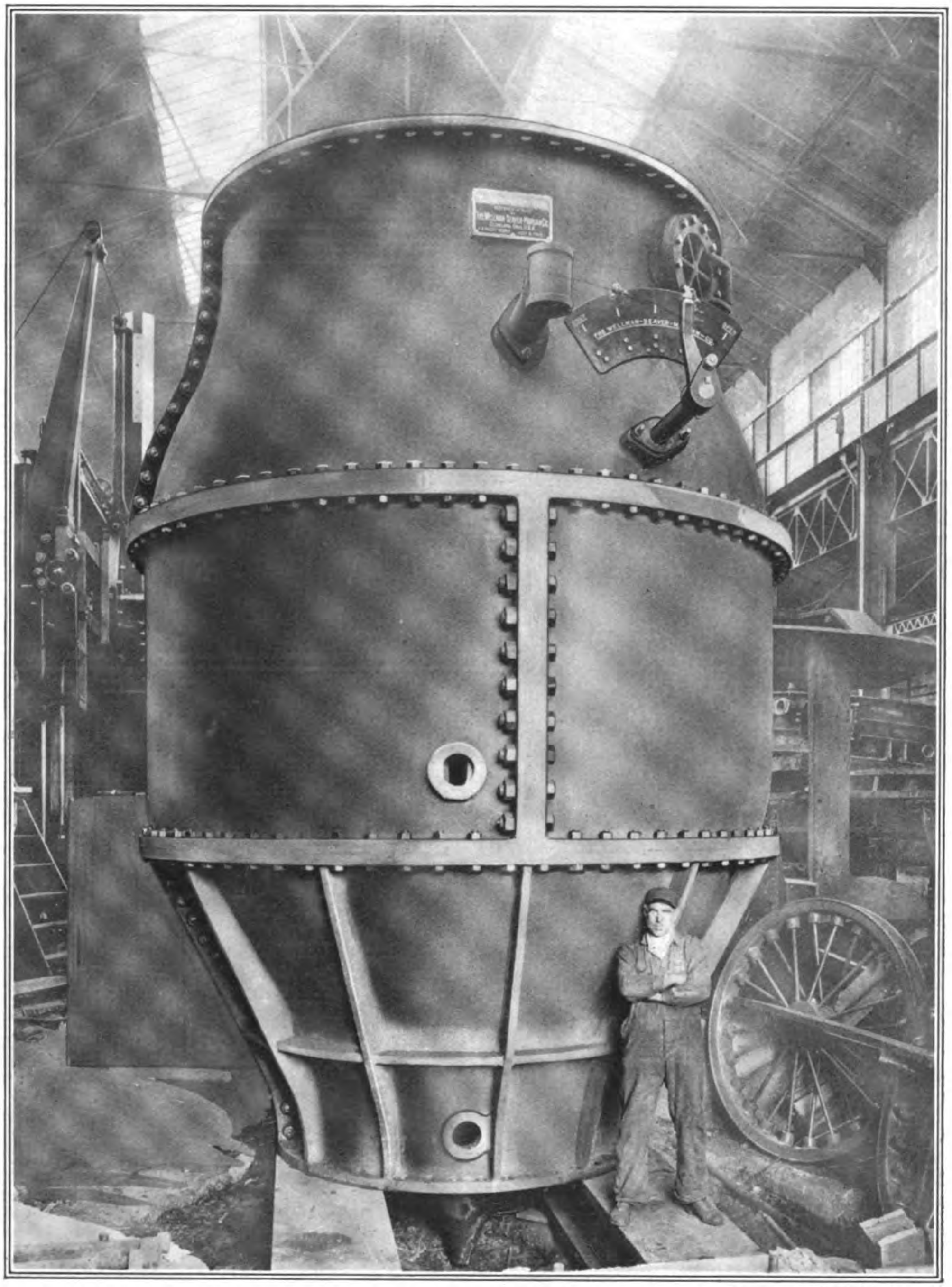
SECTIONAL ELEVATION OF POWER HOUSE OF THE ONTARIO POWER CO.

THE ONTARIO POWER CO. *of* NIAGARA FALLS



THE plant of The Ontario Power Company, at Niagara Falls, Ontario, produces more power than any other hydro-electric plant in the world. The present peak load is about 210 000 HP. The bulk of this power is delivered to the system of the Hydro-Electric Power Commission of the Province of Ontario, for distribution in Canada, and to the Niagara, Lockport & Ontario Power Company for distribution in the United States. The remainder is distributed locally among the various industries in the neighborhood of Niagara Falls, on both sides of the river.

The generating station is situated at the foot of the cliff on the Canadian side of the river, immediately below Horseshoe Falls. The water for the turbines is diverted from the river at the beginning of the upper rapids, about a mile above the falls, by a submerged diverting dam projecting from the Canadian shore. This dam is curved, sweeping into a direction approximately parallel to the shore at its outer end and forming an outer forebay, the intake to which is protected by a wall of submerged arches which acts as an ice-fender. From the outer forebay the water passes through a screen-house located at the entrance to the inner forebay. Here it is again skimmed of ice, the latter passing over the submerged dam into the rapids. From the inner forebay the water passes through the gate house into the conduits. There are three conduits, about 6300 ft. long, each provided with an elec-



NINE FT. VERTICAL NEEDLE VALVE FOR THE ONTARIO POWER CO.

DISTRIBUTING STATION

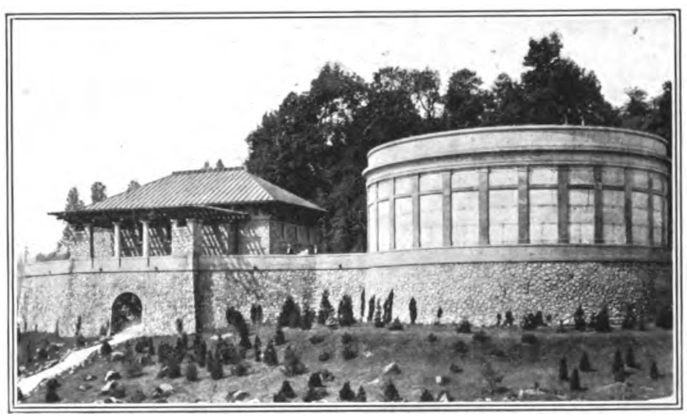
trically operated Stoney gate. Conduit No. 1 is 18 ft. inside diameter, made of steel plate, with stiffening rings and encased in concrete with an earth and rock back-fill. It passes underground through Queen Victoria Park, and terminates with an overflow weir which discharges the surplus water through a tunnel into the lower river. This weir is designed to prevent excessive pressure or water hammer, which would result from a sudden reduction of velocity in the conduit if it were a closed system.

Conduit No. 2 is built of reinforced concrete. The area of cross section is the same as No. 1, but it is oblate in shape, the vertical axis being about 3 ft. less than the horizontal. This shape is determined theoretically from the fundamental hypothesis that the stress in the walls shall be uniform when the conduit is under pressure. This condition cannot obtain in any conduit of circular cross section.

Conduit No. 2 runs parallel to No. 1, and terminates near the power house in a reinforced concrete surge tank 75 ft. diameter. This tank is of the Johnson differential type, with an internal riser and overflow weir to limit the height of the surge in case of a shutdown. It is the largest tank of its type ever built.

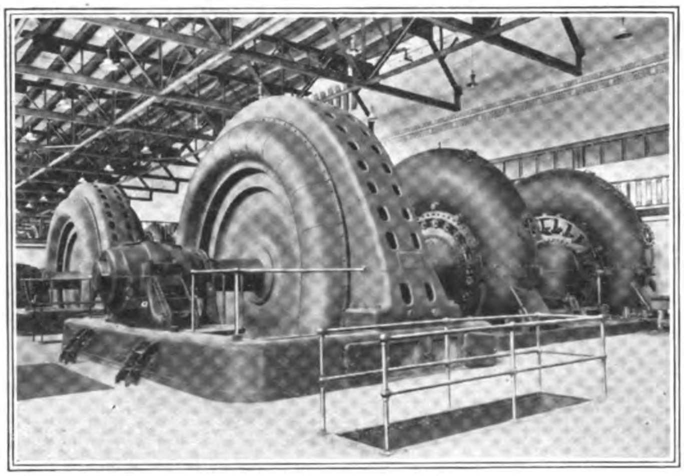
Conduit No. 3 is built of wood stave, back filled, with a steel plate surge tank at the end.

The penstocks leading from the conduits to the turbines are of plate steel, 9 ft. diameter. The penstock valves are located in a subterranean valve chamber immediately below the conduits. There are sixteen 9 ft. valves for the main units, twelve of which are motor operated gate valves, and the other four, which were the last installed, are needle valves. The latter were built by The Wellman-Seaver-Morgan Co.



SURGE TANK AND OVERFLOW

The penstocks are carried vertically to the level of the tur-



UNIT No. 14—ONTARIO POWER CO.

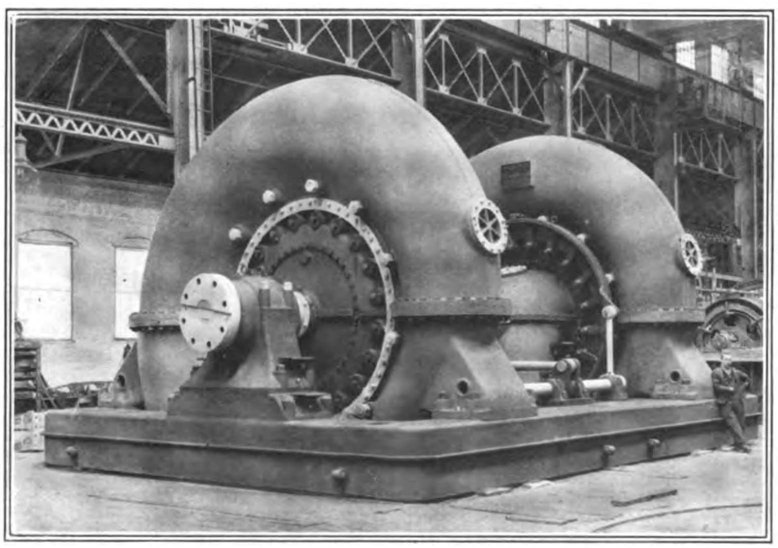
bines, and then horizontally through shafts and tunnels excavated in rock. Each penstock has two branches in the power house, connected to the turbine casings.

There are sixteen main units at present installed, two of which, Nos. 12 and 14, were built by The Wellman-Seaver-Morgan Company. These turbines are of the horizontal double-spiral central-discharge type. The rated capacity is 13 400 HP each, at which load they are designed to give maximum efficiency. The maximum output is 15 000 HP. They operate at a speed of 187.5 RPM under a net effective head of 180 ft.

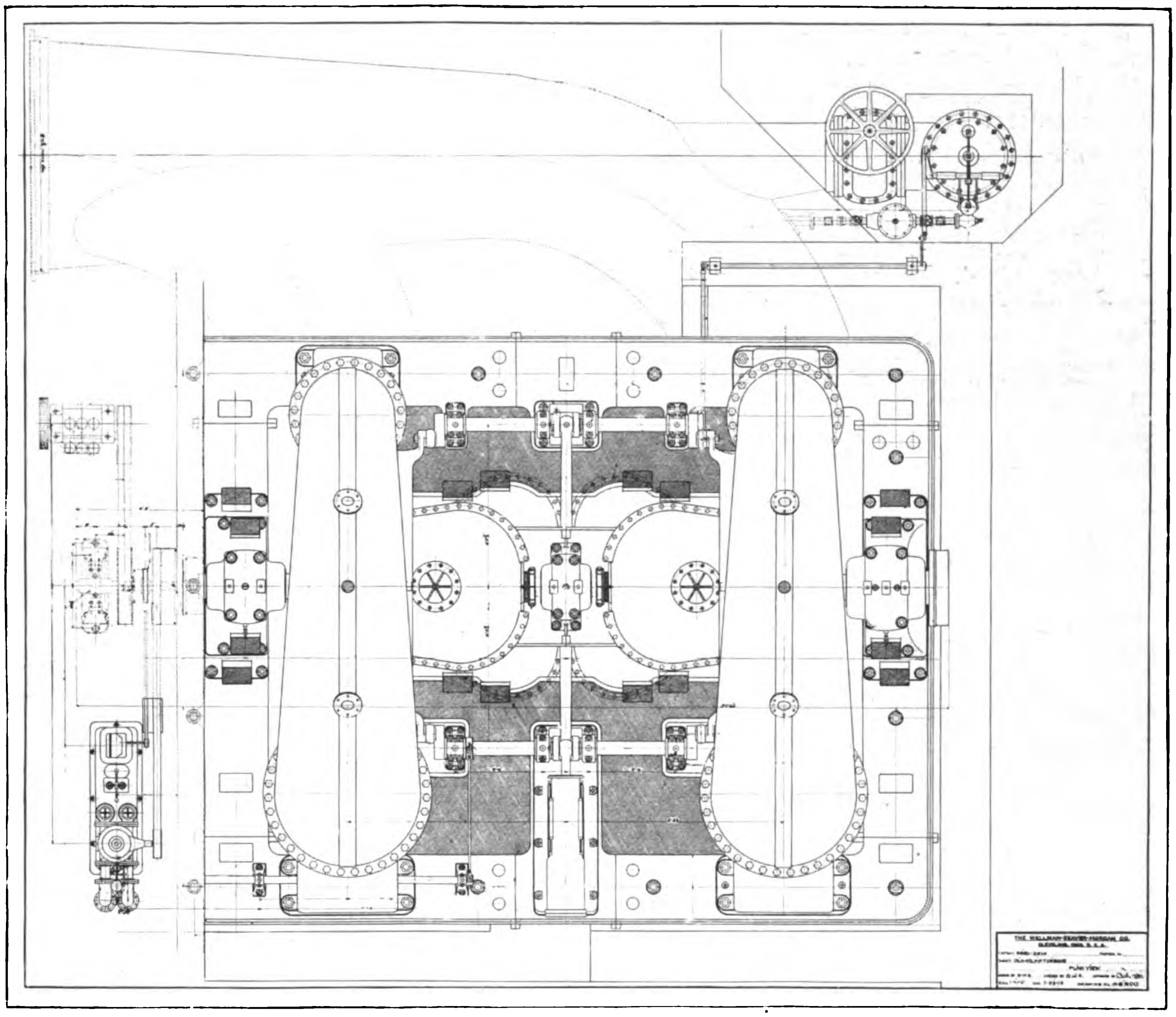
The turbine casings are cast steel, and were at the time of installation the largest cast steel spirals built. The runners are of bronze, 88″ diameter. Both runners discharge into a common draft tube. The upper part of the draft tube is cast iron to prevent erosion, and the remainder is concrete. The entire unit, consisting of spiral casings, discharge case, bearings, gate mechanism, and governor regulating cylinder, is mounted on a massive cast iron bed plate imbedded in the floor.

The shaft is in one piece, bolted to the runner hubs. There are three bearings, all of the ring-oiling self-aligning type. The thrust bearing, which is next to the generator, is water-cooled.

The gate mechanism is operated in balance by a single regulating cylinder or servo-motor. The gates are of the balanced wicket type. They are steel forgings machined all over. All rods and links of the gate mechanism are of adjustable length and are thoroughly lubricated. The gate-stem packings are designed not only to exclude water and grit, but to retain the lubricant. Both ends of the gate-stems are exposed to atmospheric pressure, to prevent an unbalanced hydraulic thrust.



SHOP VIEW OF 15 000 HP TURBINE



PLAN VIEW OF 15 000 HP TURBINE

The governors are located on the operating gallery. They are special actuators designed for this installation by the Lombard Governor Company. They operate on an open oil system at 200 pounds pressure. The pumps and tanks are under the gallery, on the same level as the turbines.

Each unit is provided with a 30″ synchronous governor-operated pressure regulator or relief valve. These valves operate by penstock pressure, and require no independent pressure supply of either oil or water. They are separately described in this catalogue.

The generators are horizontal direct-connected alternators, 3 phase, 25 cycles, 12 000 volts. They are ventilated by forced draft. The fans are located in the basement under the main floor.

There are two turbine-driven exciters, each consisting of a 1600 HP horizontal turbine direct connected to a 900 KW, 2200 volt, 3 phase, 25 cycle, 375 RPM generator which is in turn connected to a 2200 volt induction motor and a 125 volt D. C. generator.

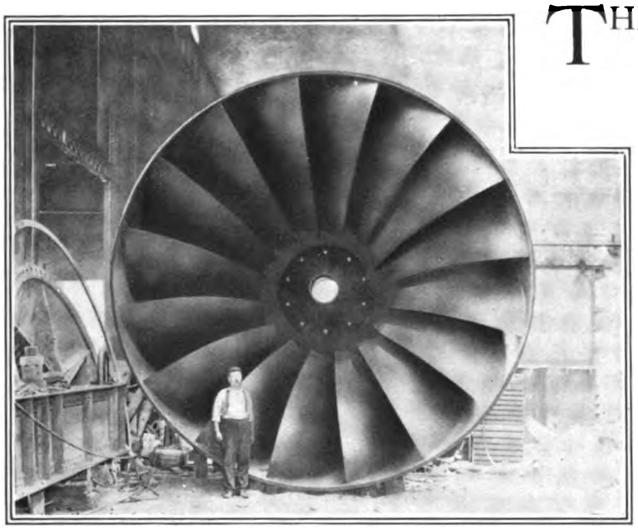
Each main unit has an individual exciter set consisting of a 75 HP induction motor driving a 60 KW D.C. generator, and the ordinary function of the turbine driven exciters is to furnish alternating current to drive the individual exciters. In case of accident to the exciter turbines, the D. C. generators may be driven by the A. C. motors, current for the latter being obtained from the main circuits.

The distributing station is located on top of the hill, above the power house. The cables from the power house reach it through tunnels containing tile ducts. There are two sets of cables for each generator.

The distributing station contains the high and low tension busses, 12 000 volt oil switches, and the 12 000 to 60 000 volt transformers. The control room is isolated in the upper part of the building, as far removed from sources of disturbance as practicable. It contains controlling and indicating apparatus for all of the generating and transforming units, switchboards and voltage regulators. All regulating of generating units and switching of load in the power house is governed from the control room. The distributing station and power house are reached from the ground level at the top of the cliff by tunnels and elevators.

This plant, when built, represented the most advanced practice in hydro-electric development. No expense was spared to make it, in point of efficiency and reliability of service, one of the finest installations in the world.

CEDARS RAPIDS MFG. & POWER CO.

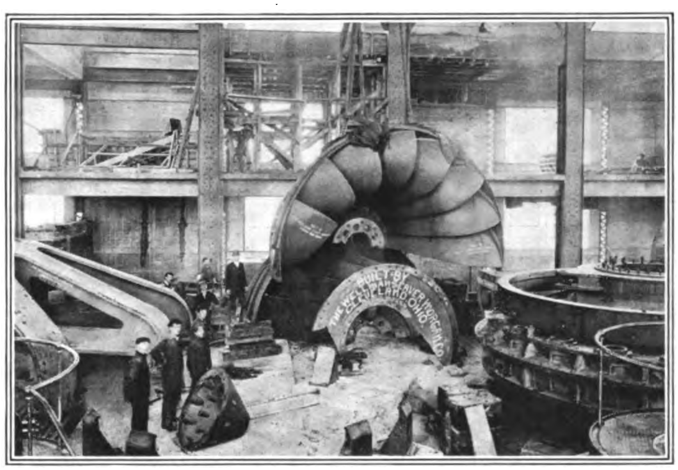


RUNNER FOR 10 800 HP TURBINE.
LARGEST TURBINE RUNNER EVER BUILT

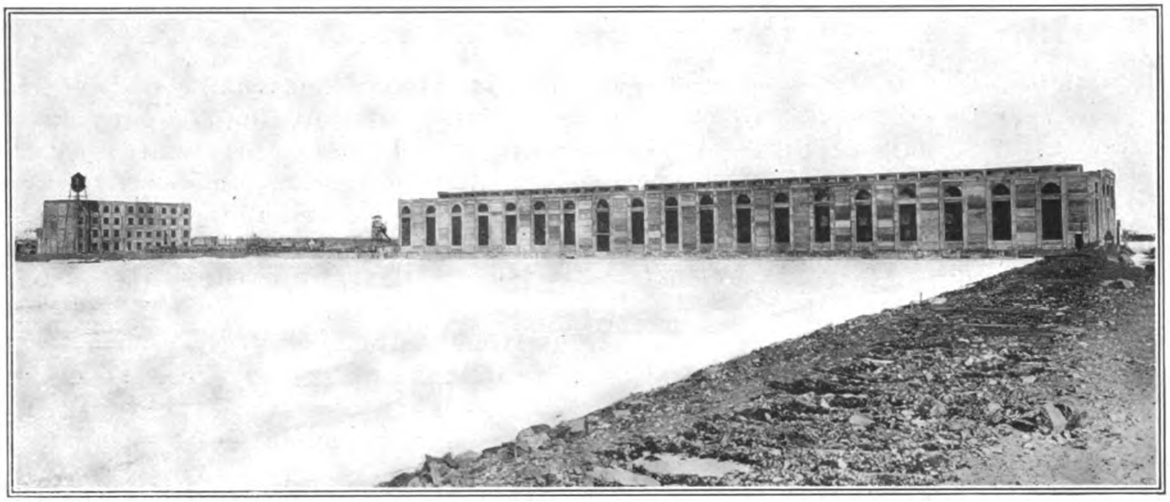
THE plant of the Cedars Rapids Manufacturing & Power Company is located at Cedars Rapids, on the St. Lawrence River, about eight miles west of Vaudreuil, Quebec, and when completed will have a capacity of about 180 000 HP. This plant will then have the third largest output in Canada. The larger plants being the Ontario Power Co. of Niagara Falls and the Queenston Development of the Hydro-electric Power Commission of Ontario. Both of the latter plants contain W-S-M turbines. The installation, in physical magnitude, will exceed by far any other Canadian plant. This company is closely identified with the controlling interests of the Shawinigan Water & Power Company and The Montreal Light, Heat & Power Company. The principal part of the initial output is used for electro-chemical purposes. Transmission lines have been built to Montreal and Massena, N. Y., the latter for the use of The Aluminum Company of America. The Cedars Rapids plant is built adjacent to the north shore of the St. Lawrence River, and interferes in no way with navigation. The water for the plant is drawn from the river above Cedars Rapids through a canal formed by an earth dyke built parallel to the north shore of the river. This canal or head race is about four miles long. The main channel of the river is not dammed or obstructed in any way. Only part of the flow of the river is delivered to the power house. The width of the canal varies from a mean of about 700 ft. to 1200 ft. at the power house. It is designed for a flow of 56 000 cu. ft. per second. The power house when completed for the final installation, will be about 1200 ft. long by 132 ft. wide.

The ultimate installation will consist of eighteen 10 800 HP main units and four 1500 HP exciter units.

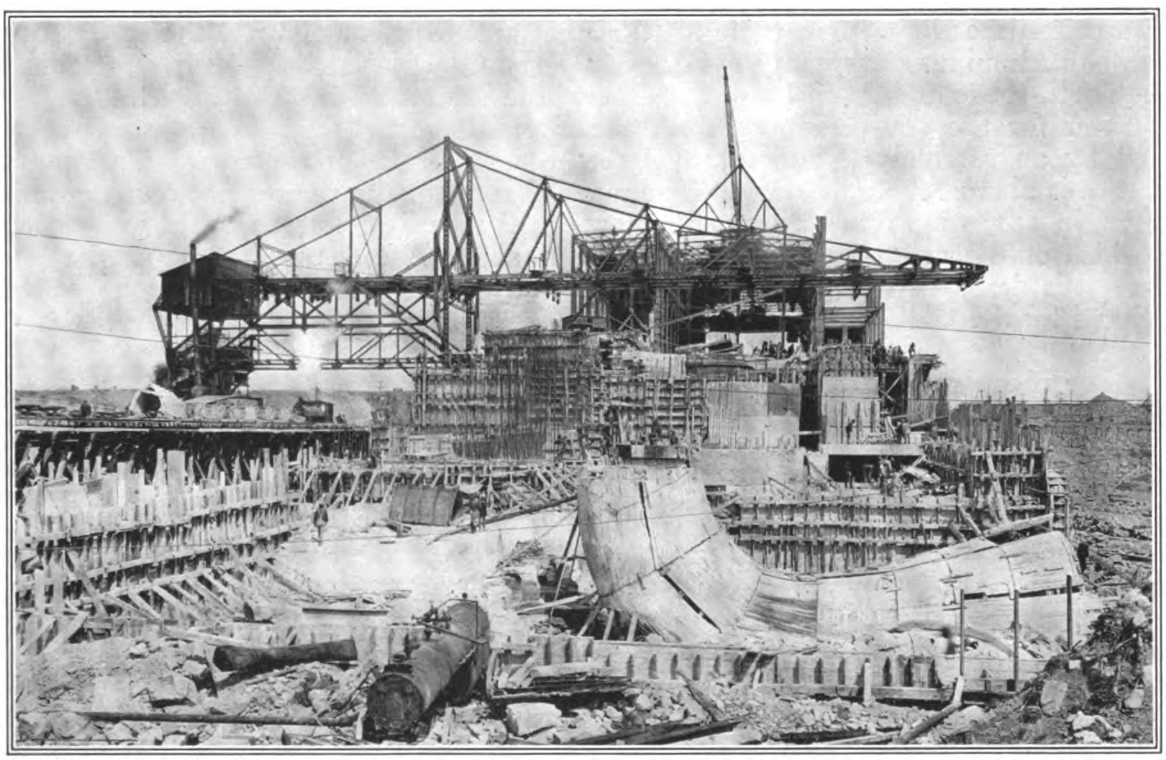
Three of the main units were built by The Wellman-Seaver-Morgan Company. These units operate at a speed of 54.3 RPM under a net effective head of 30 ft. They are of the single-runner vertical type, the weight of the rotating parts of both turbines and generators being carried on thrust bearings located above the generators. The thrust bearing sup-



ASSEMBLING RUNNER IN POWER HOUSE



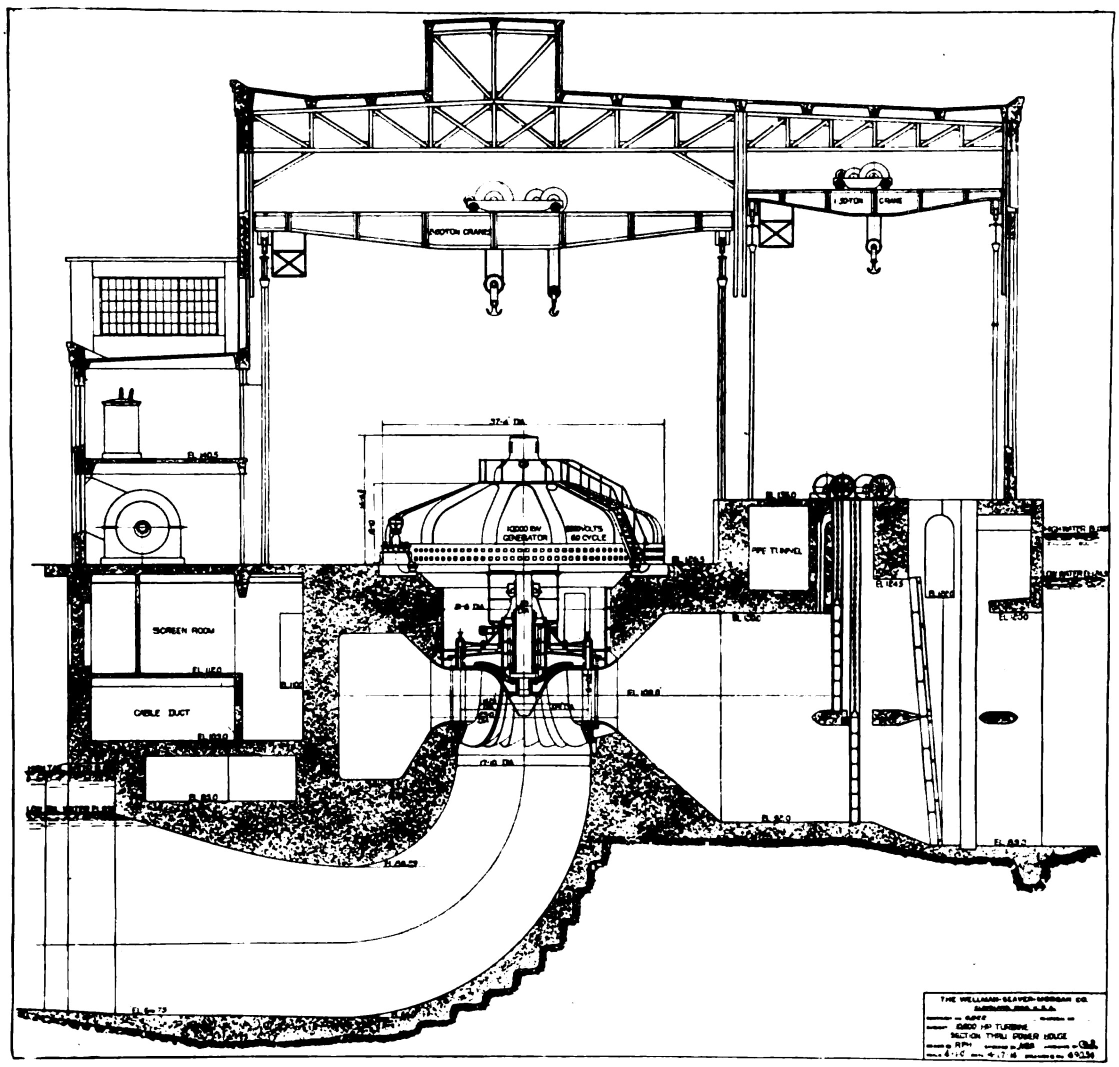
POWER HOUSE OF THE CEDARS RAPIDS MFG. & POWER CO.
ON THE ST. LAWRENCE RIVER, NEAR CEDARS, QUE.



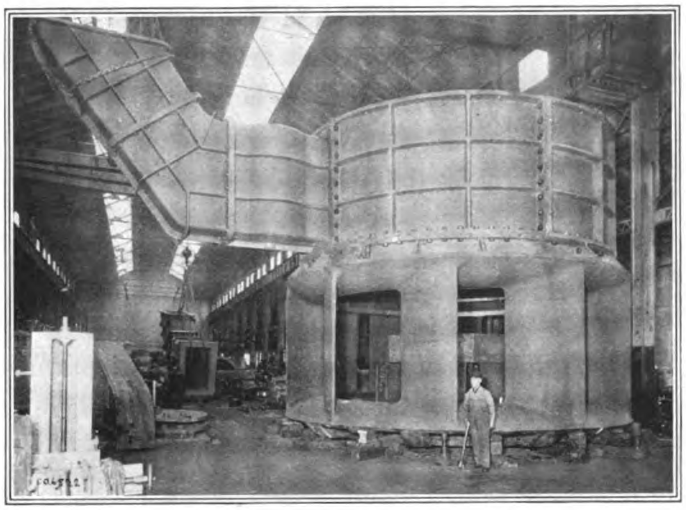
POWER HOUSE DURING CONSTRUCTION

ports, which rest on the frames of the generators, were furnished as a part of the turbine equipment.

These turbines are the largest of their type which have, so far, been built, exceeding somewhat in size the single-runner vertical turbines built by this company for the Mississippi River Power Company. The runners are of cast iron, built in halves. The maximum diameter is 17 ft. 8 in. They were cast in one piece, but it was necessary to split them in halves for transportation. The two halves are bolted together and reinforced by a heavy cast steel ring around the band, and a cast steel cover plate forming the hub of the runner to which the shaft is attached. The total weight of the runner assembled is about 160 000 pounds.



SECTIONAL ELEVATION OF CEDARS RAPIDS POWER HOUSE



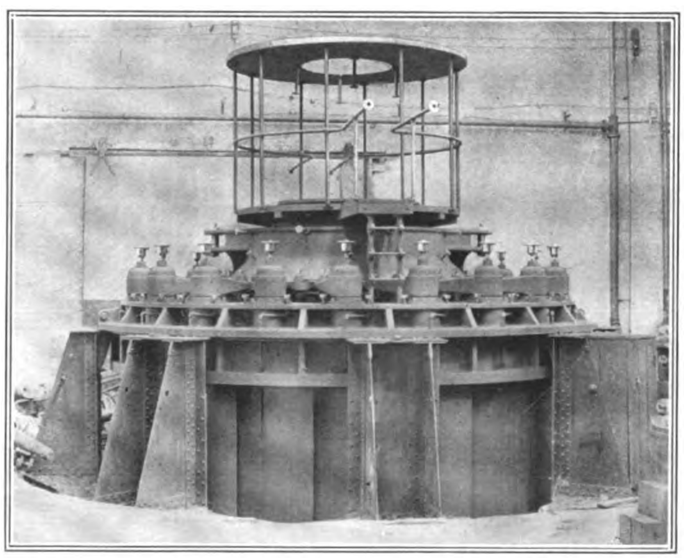
PIT LINER AND STAIRWAY TUNNEL FOR 10 800 HP TURBINE

The gates are of the balanced wicket type, made of cast steel, with removable forged steel stems or fulcrums. These stems are connected by levers and links of adjustable length, to a rigid cast steel operating ring, directly connected at two diametrically opposite points to two regulating cylinders or servo-motors. These cylinders are attached to the cast iron pit liner between the turbine and the generator. This pit liner is of cylindrical form, surmounting the speed-ring which supports the crown plate of the turbine, and forms a distributor for the water entering the turbine gates. The speed-ring is in turn mounted on the draft tube ring or collar which forms the upper section of the draft tube. The draft tube is formed in concrete, and the draft tube ring is provided to prevent erosion of the upper end of the draft tube by the water as it leaves the runner. The pit liner has an opening which connects to a cast iron tunnel with steps leading from the generator floor into the wheel pit. This tunnel is provided with a revolving door in order that all cooling air supplied to the generator shall be drawn from the ducts beneath the floor provided for that purpose.

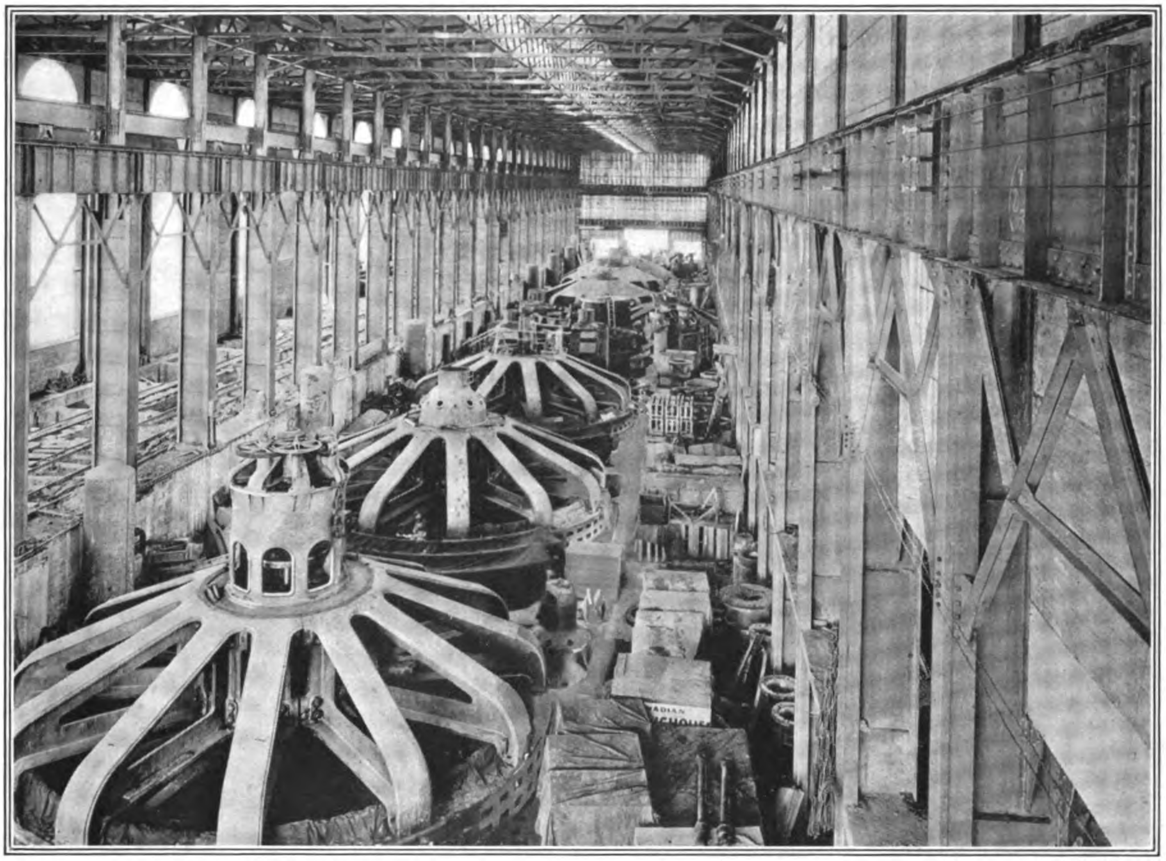
Six friction brakes acting on the bottom face of the generator rotor are mounted on the bedplate of the generator. They are operated by compressed air and are used to stop the unit after the turbine gates are closed.

The main turbine bearing is of the lignum-vitae type provided with water circulation. There is no other bearing between the turbine and the rotor of the generator. An oil-lubricated guide bearing, however, is provided in the thrust bearing support above the rotor.

The design of the thrust bearing support is especially interesting in view of the unusual span and the great weight to be supported. The outside diameter of the generator frame is approximately 37 ft., and the total weight of the rotating parts of the unit is about 550 000 pounds. In addition to this, the weight of the support itself is about



SHOP ASSEMBLY OF GATE MECHANISM AND CROWN PLATE OF 10 800 HP TURBINE



CEDARS RAPIDS POWER HOUSE, DURING ERECTION OF GENERATORS AND THRUST BEARINGS

300 000 pounds. The support consists of a central cast iron hub to which twelve cast iron arms are bolted, forming a spider which rests on the frame of the generator. The thrust bearings are of the Kingsbury and General Electric spring type, the Kingsbury, consisting of eight segmental shoes babbitted on the top surface, and each supported on a single adjustable pivot. A massive cast steel thrust block is keyed to and held in position at the upper end of the shaft by a circular key or keeper. The lower face of this block has a polished cast iron annular ring bolted to it for bearing on the babbitted shoes. This bearing is provided with a constant circulation of oil, and runs in an oil bath, no pressure system being required. The bearing and thrust block are enclosed in a housing provided with glass sight holes, and lighted inside with electric lights in order that the operation of the bearing may be readily inspected at all times. The thrust bearings on the last three units installed are of the General Electric Co.'s spring type described elsewhere in this catalogue.

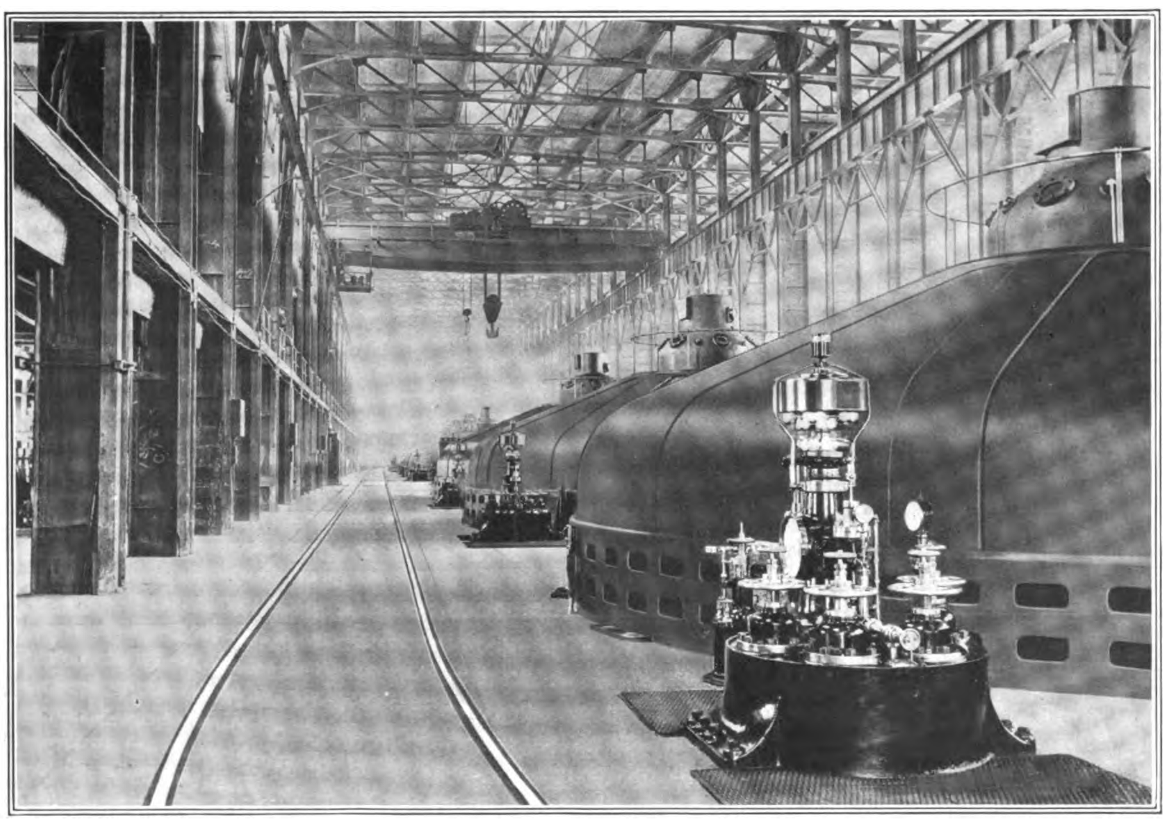
The governors are located on the generator floor and are driven by geared counter-shafts from the main shaft of the turbine. They are supplied from a central pumping system with water at 200 pounds pressure. All parts of the governors and operating cylinders which come in contact with the water are bronze lined. The pressure pumps are of the multiple-stage centrifugal type, motor driven. Each unit has an individual pressure tank, and is equipped with a device for hand operation independent of the governors. The latter may be controlled by hand, either locally or from the switchboard. The water

discharged by the governors is returned to the central sump through a copper-lined conduit encased in concrete. This conduit is installed in duplicate, and is large enough to permit an operator to enter for the purpose of cleaning.

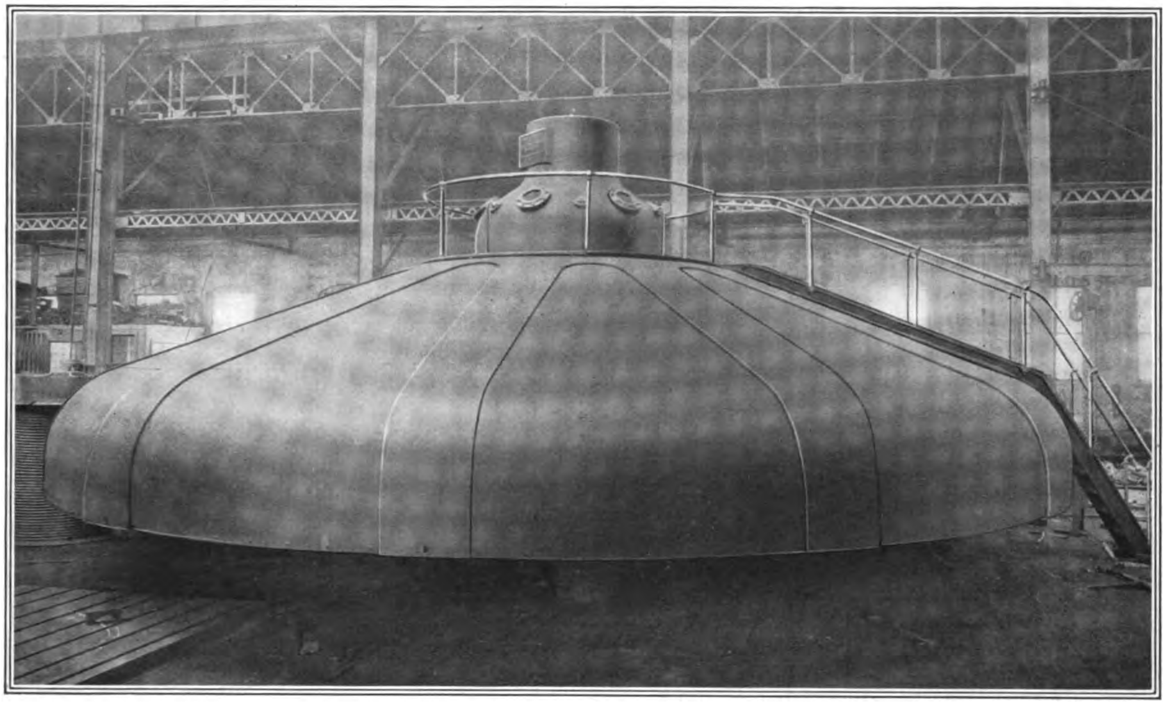
The over-all height of these units is 43 ft. 2¾ in. and the total weight including the generators, 1 615 000 pounds.

The turbines are supplied with water by wheel chambers of spiral form moulded in the concrete foundations of the power house. These wheel chambers have two piers at entrance, dividing the intake into three channels. Each channel is provided with two structural steel head gates. The lower head gate extends from the bottom of the intake to a concrete partition or beam projecting horizontally across the entrance. The upper head gate extends from this beam to the top of the intake. These gates are provided with separate motor driven hoisting apparatus. The racks are located in front of the head gates, and may be raised by a traveling crane running the length of the gate house.

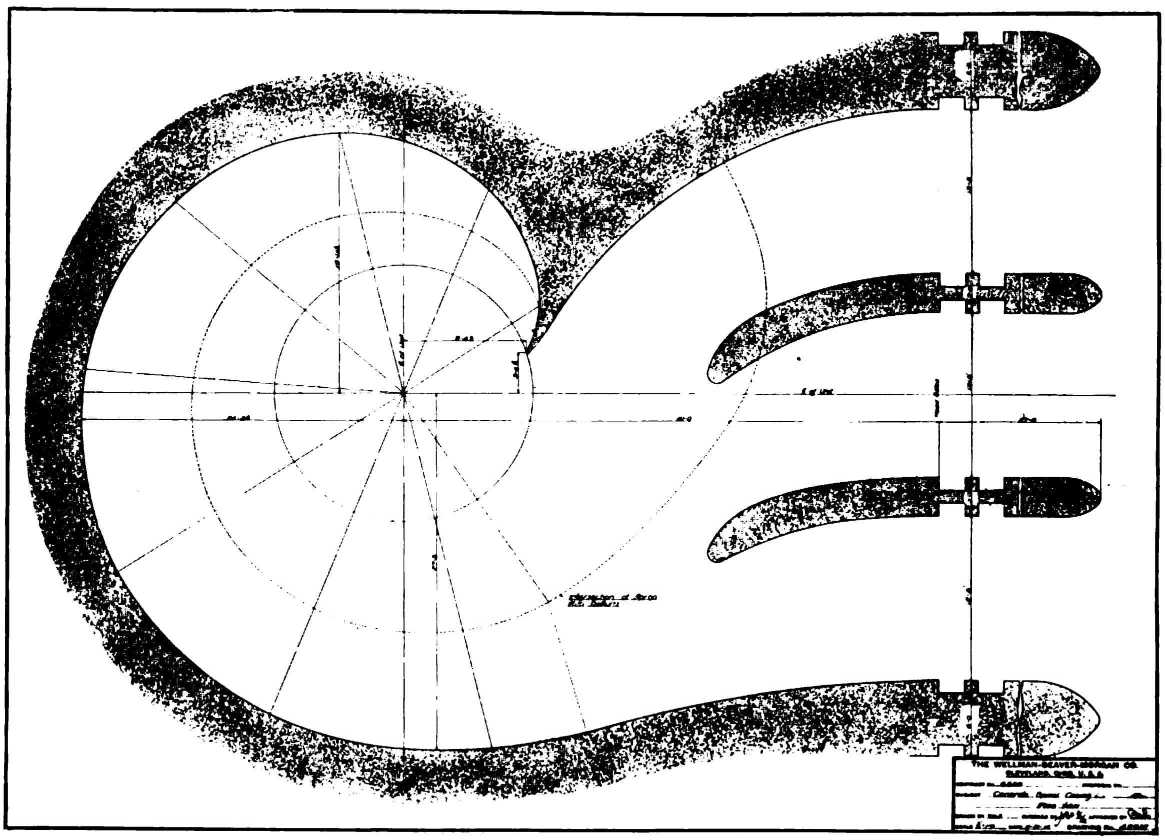
In the design of this plant a special effort has been made to place all of the auxiliary apparatus within convenient access of the station operators on the main floor of the plant. The turbines and thrust bearings are readily reached by stairways from this floor. The governors and tanks are located on the floor, and the central system pumps are in an open pit at the center of the station.



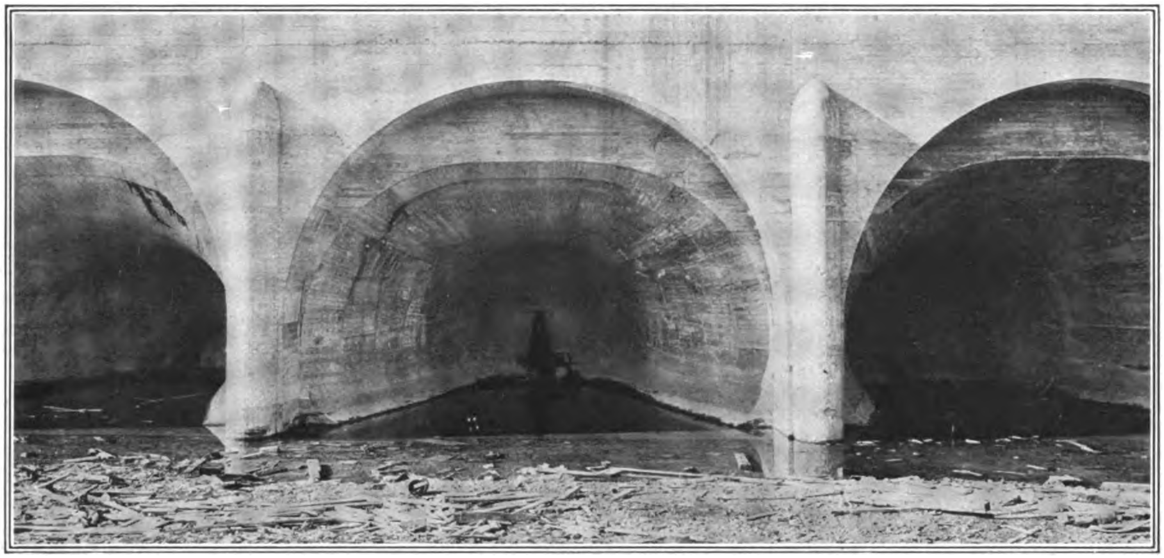
CEDARS RAPIDS POWER HOUSE IN OPERATION



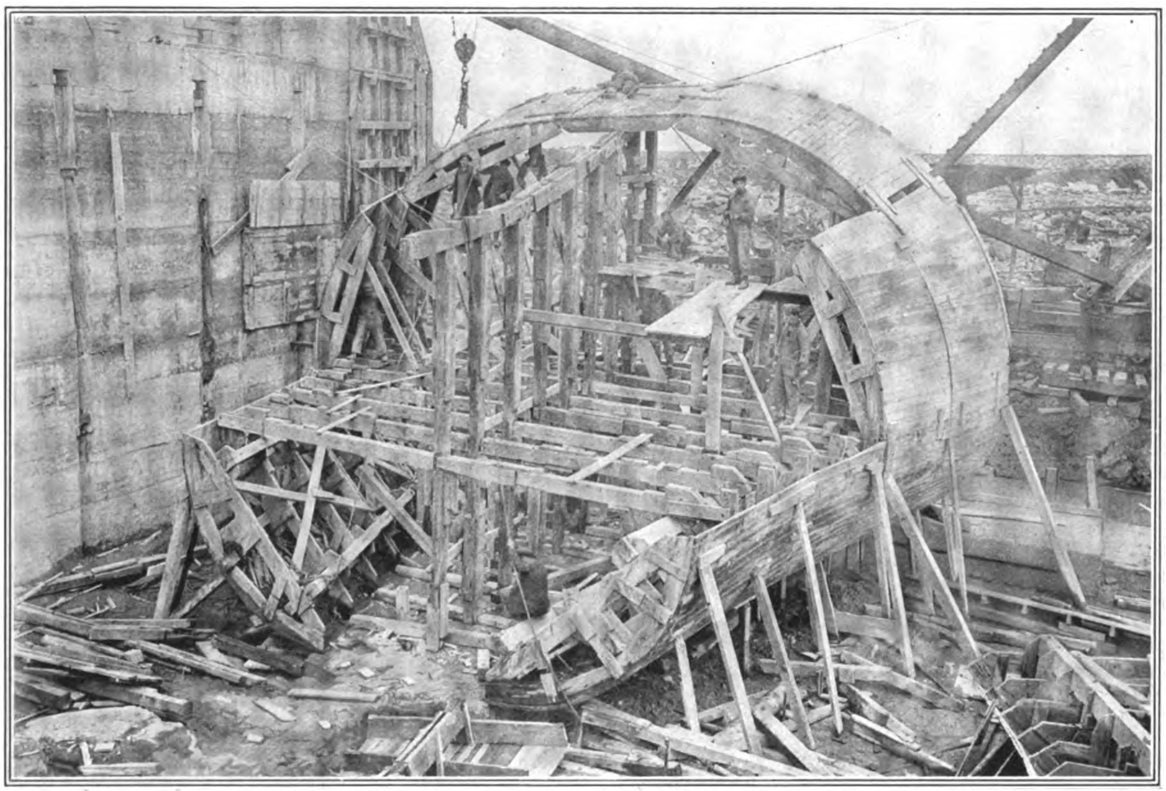
THRUST BEARING SUPPORT FOR 10 800 HP TURBINE



SECTIONAL PLAN OF CEDARS RAPIDS WHEEL CHAMBERS

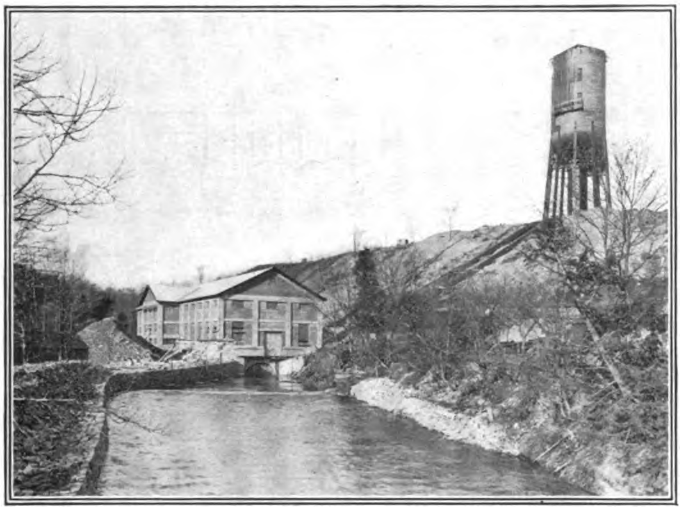


DRAFT TUBE OUTLETS—CEDARS RAPIDS POWER HOUSE



CONSTRUCTING FORMS FOR CEDARS RAPIDS DRAFT TUBES

THE SALMON RIVER POWER COMPANY



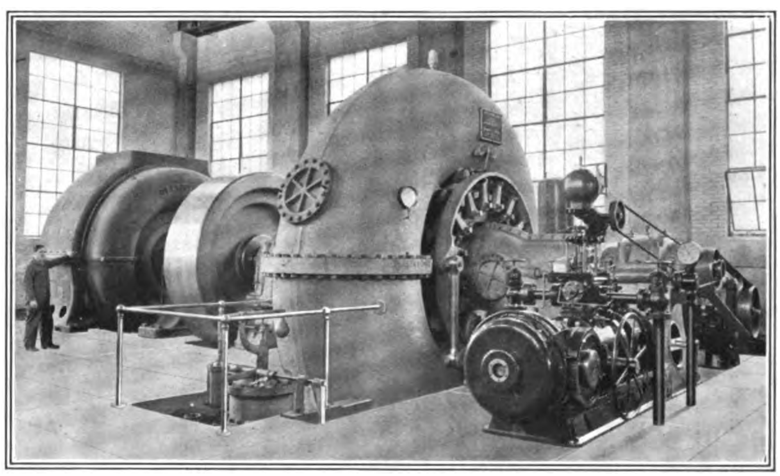
SALMON RIVER POWER HOUSE AND SURGE TANK DURING CONSTRUCTION

THE hydro-electric development of the Salmon River power Company, on the Salmon River, near Altmar, N. Y., is one of the most interesting in the country. The natural conditions and many features of the installation are quite unusual, especially in the eastern part of the United States.

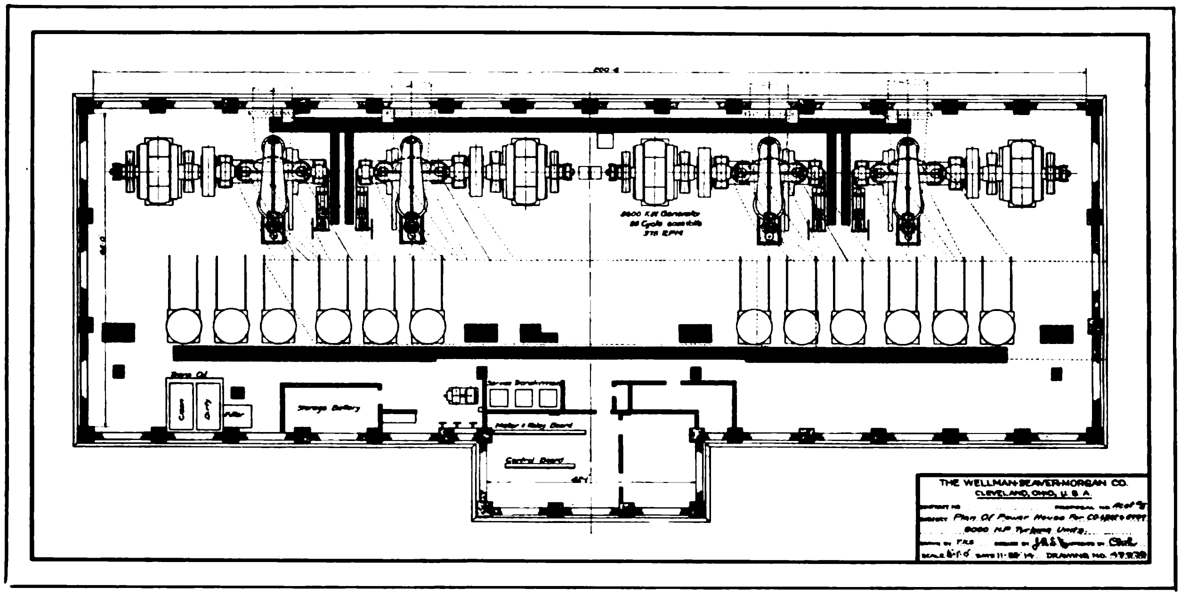
The Salmon River is one of the most important sources of water power in New York State. In fact, it ranks next to Niagara. Although only 40 miles long, this river drains a watershed of 190 square miles, having an average yearly rainfall of approximately 60 in. There is a drop of 650 ft. in about 17 miles, and the present development obtains an average net head of 245 ft. in a distance of about 10 000 ft. measured along the pipe line.

The dam is of concrete and forms a storage pond about 5½ square miles in area. The conduit leading to the surge tank consists of an initial section of tunnel 600 ft. long and 12 ft. diameter through rock, an intermediate section of wood stave pipe 7825 ft. long, and a final section of riveted steel pipe 1200 ft. long, terminating in a 12 ft. diameter riveted steel distributor 210 ft. long. This distributor is connected at the center by a vertical 12 ft. diameter riser to the surge tank. It also has four branches to the 8 ft. diameter penstocks leading down the hill to the power house.

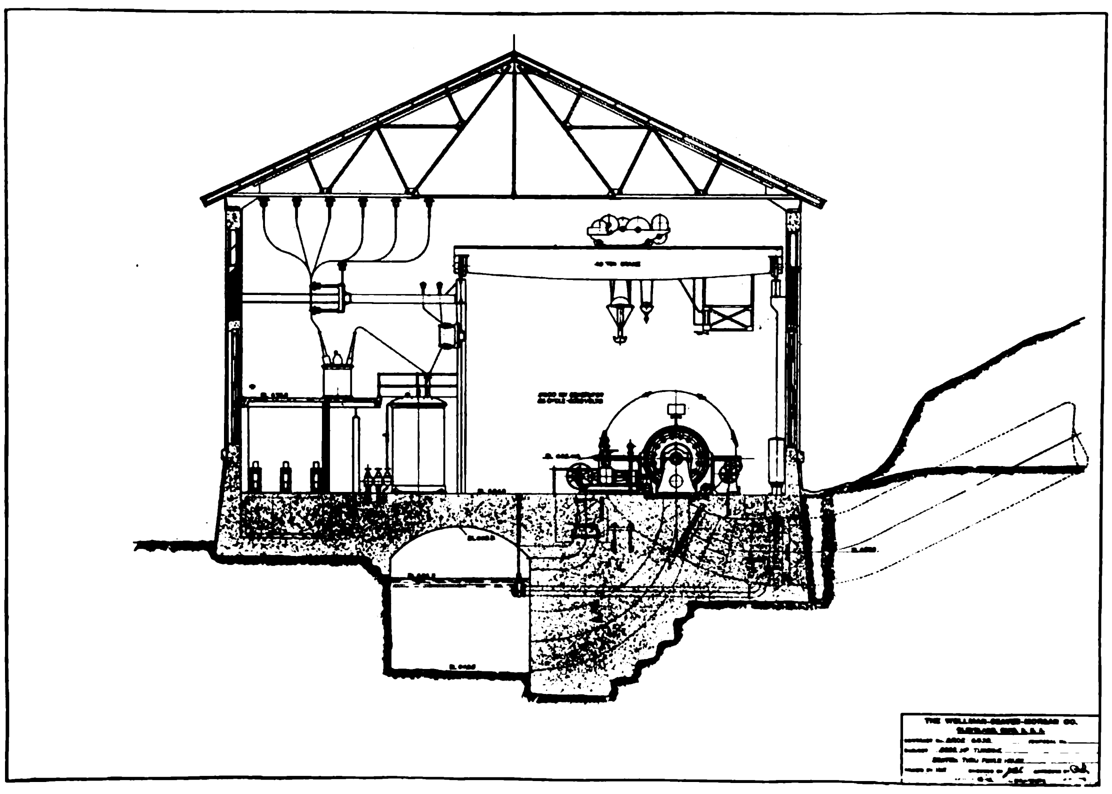
The surge tank is of the Johnson differential type, and is the largest in the United States. It consists of a tank 50 ft. diameter and 80 ft. high, with a hemispherical bottom and an internal riser.



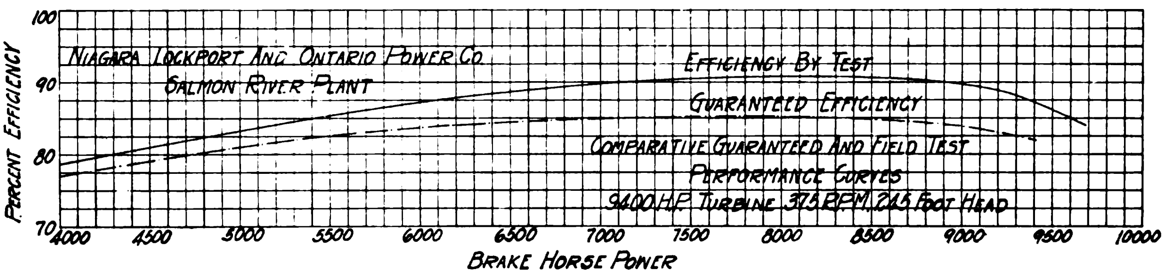
10 000 HP TURBINE UNDER 245 FT. HEAD
SALMON RIVER POWER CO.

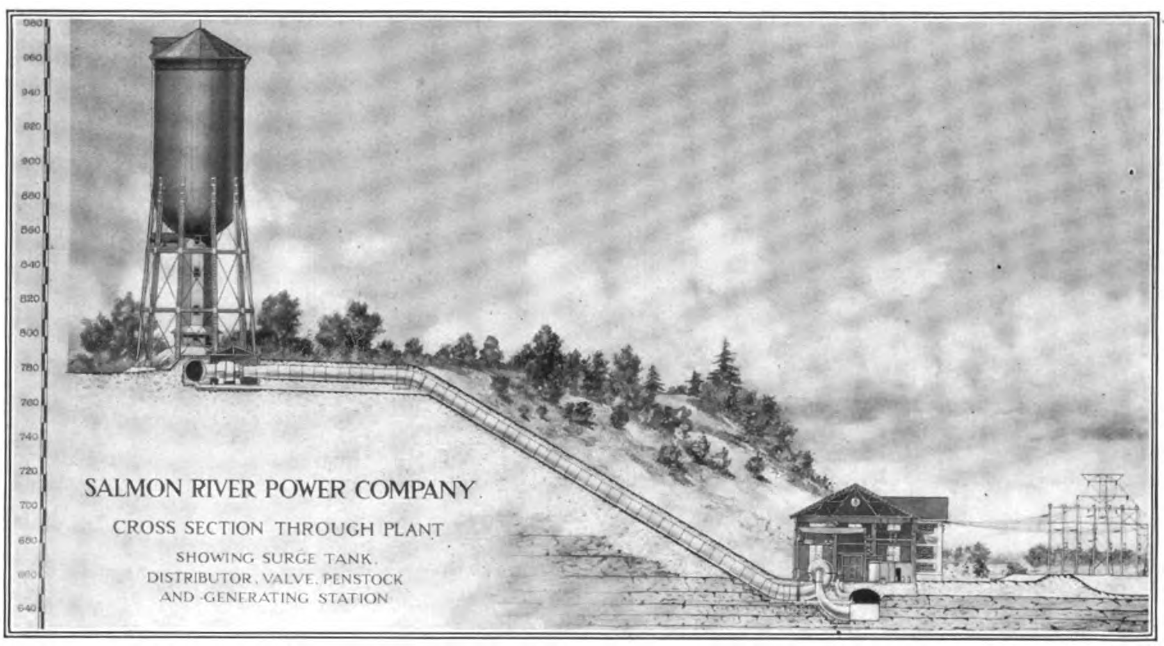


PLAN VIEW OF SALMON RIVER POWER HOUSE



SECTIONAL ELEVATION OF SALMON RIVER POWER HOUSE

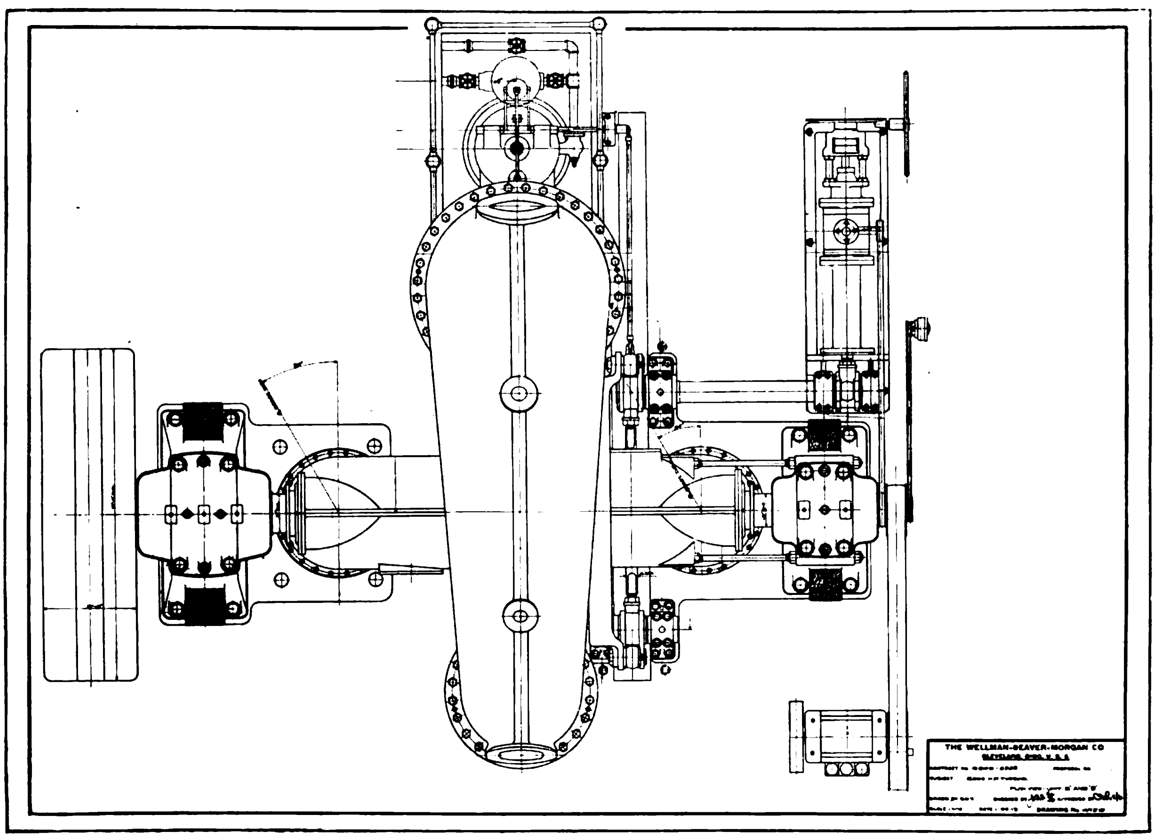

NIAGARA LOCKPORT AND ONTARIO POWER CO.
SALMON RIVER PLANT
EFFICIENCY BY TEST
GUARANTEED EFFICIENCY
COMPARATIVE GUARANTEED AND FIELD TEST
PERFORMANCE CURVES
9400 H.P. TURBINE 375 R.P.M. 215 FOOT HEAD
PERCENT EFFICIENCY
100
90
80
70
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
BRAKE HORSE POWER


SALMON RIVER POWER COMPANY.
CROSS SECTION THROUGH PLANT
SHOWING SURGE TANK,
DISTRIBUTOR, VALVE, PENSTOCK
AND GENERATING STATION

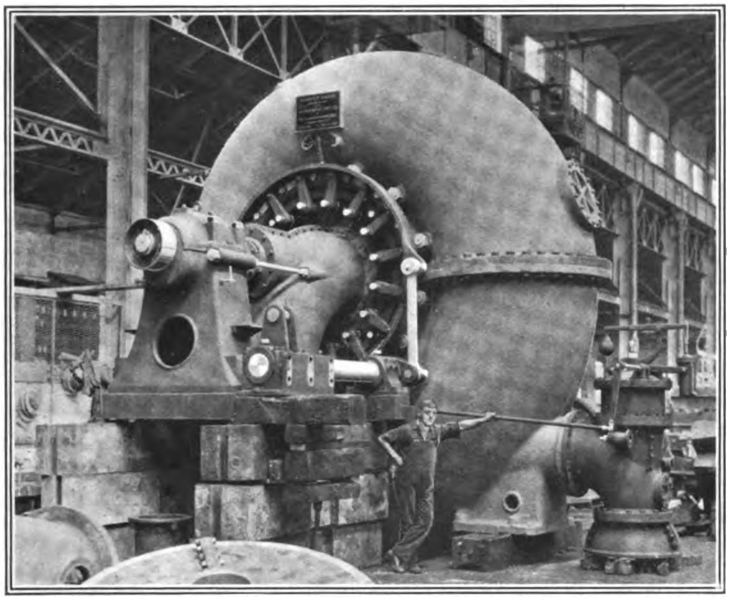
The tank is supported on structural steel columns, and the top of it is 205 ft. above the ground. This tank is designed to regulate the head on the turbines within close limits notwithstanding large changes of velocity in the conduit due to load changes on the turbines.

The penstock valves are located in two valve chambers at the base of the surge tank and immediately adjacent to the distributor. They are of the horizontal needle type, built by The Wellman-Seaver-Morgan Company. They are operated by penstock pressure independent of other sources of power. These valves are equipped for local hand control and remote electrical control. They may be operated from the power house switchboard.

The generating equipment in the power house consists of four 10 000 HP horizontal double-discharge spiral-casing turbines, built by The Wellman-Seaver-Morgan Company, and connected to 6600 volt, 25 cycle, 5600 K.V.A., 3 phase generators with direct connected exciters. These units operate over a range of head from 225 ft. to 275 ft. at a speed of 375 RPM. They are controlled by 30 000 ft. pound direct-connected Lombard governors.



PLAN VIEW OF 10 000 HP TURBINE

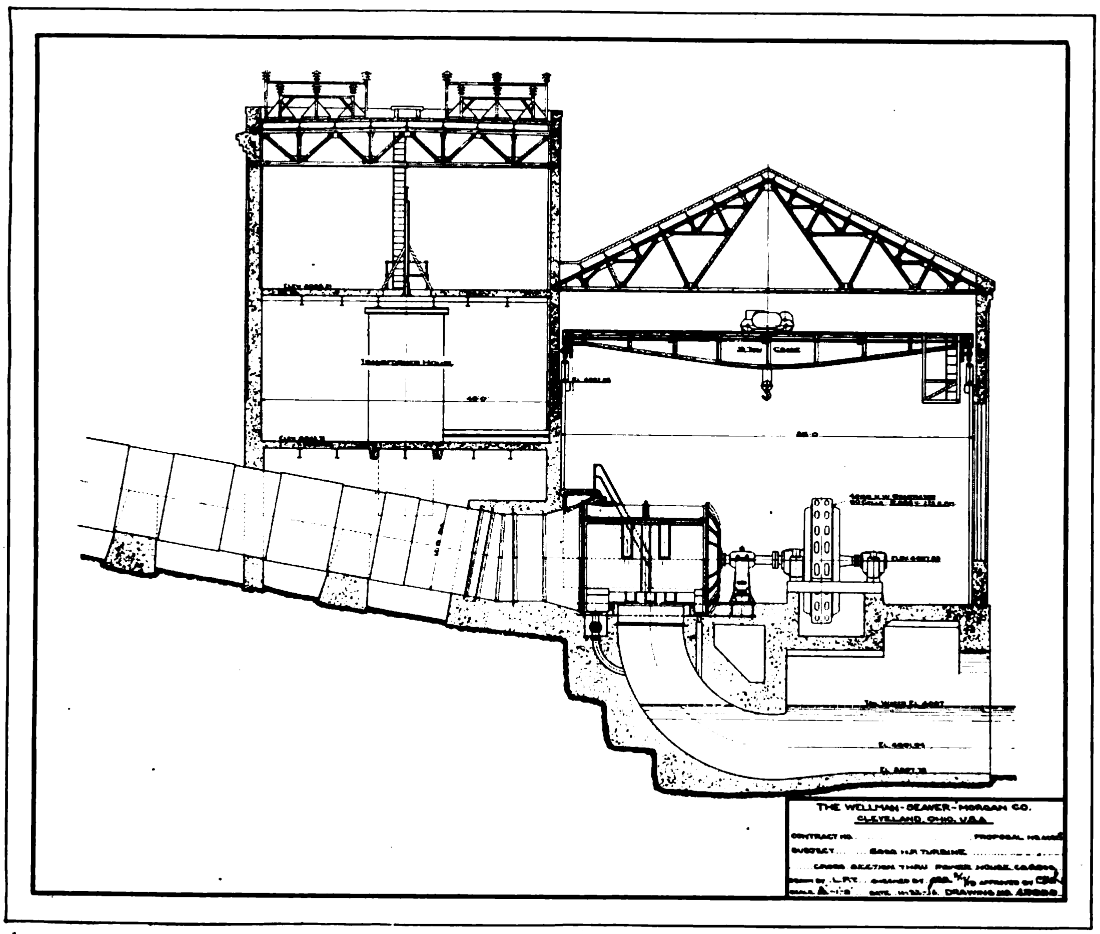


SHOP VIEW OF 10 000 HP TURBINE
FOR SALMON RIVER POWER COMPANY

This plant is notable for the unusual provisions made to secure close speed regulation. The surge tank is designed to regulate the pressure in the conduit within close limits, and each turbine is equipped with a governor operated pressure regulator to provide against fluctuations of pressure in the penstocks between the surge tank and power house. In addition to these features, each unit has a massive cast steel flywheel to facilitate the speed regulation. These flywheels weigh 85 000 pounds each, and are the largest which have ever been built for a similar purpose.

The turbine casings are cast steel, of spiral form. The runners are double-discharge, cast in one piece, of bronze.. The shaft is of a special grade of heat-treated carbon steel designed to resist crystallization. This is an important point in connection with shafts carrying a load at the center and therefore subjected to unusual bending stresses.

Both main shaft bearings are ring-oiling, self-aligning and water-cooled. The thrust bearing is at the outboard end of the turbine. The gates are of the balanced wicket type made of forged steel and machined all over. They are operated in balance from a rotating gate-shaft direct-connected to the governor. The gates may be operated by hand with oil pressure, and also mechanically. Each unit has an individual pressure and discharge tank for the governor system, interconnected, and an individual pressure pump.



CALGARY POWER COMPANY
SECTIONAL ELEVATION OF POWER HOUSE

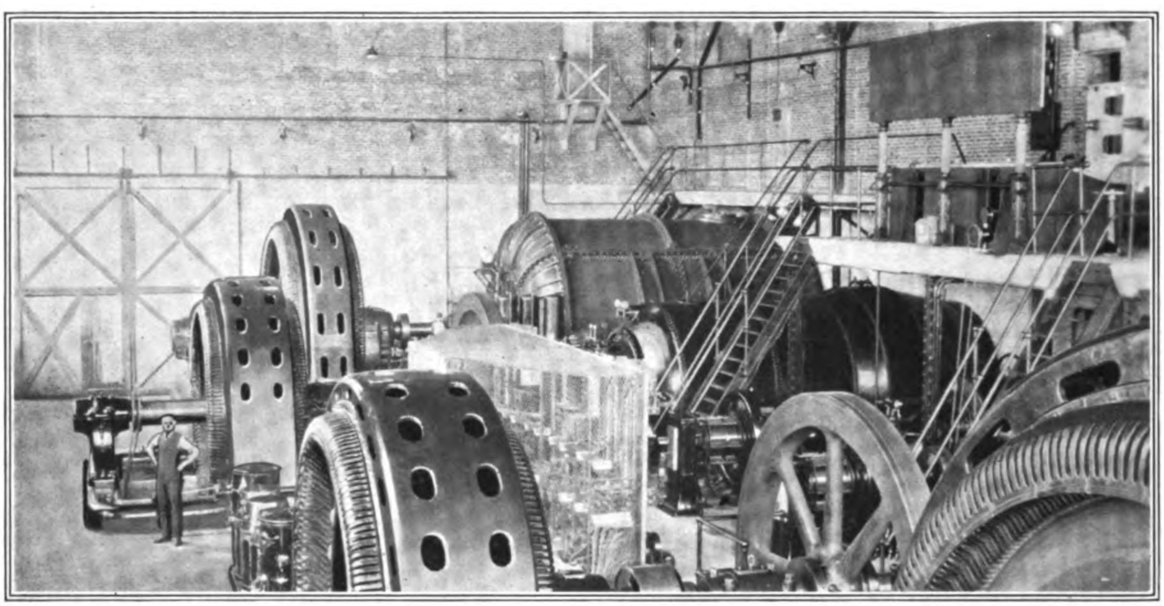
THE CALGARY POWER COMPANY

HYDRO-ELECTRIC DEVELOPMENT OF THE CALGARY POWER CO.

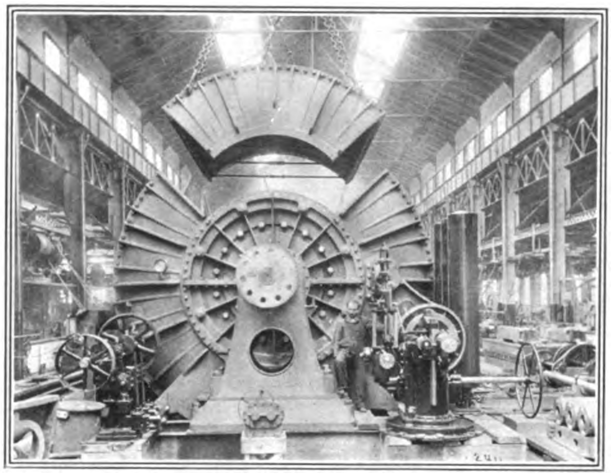
THE plant of The Calgary Power Company is located at Horseshoe Falls, on the Bow River, near Kananaskis, Alberta. It is about fifty miles west of Calgary, to which electric current is supplied over duplicate transmission lines.

This plant operates under a normal head of 70 ft. and has a capacity of 20 000 HP. There are four riveted steel penstocks 250 ft. long, two of them being 12 ft. diameter and the other two 9½ ft. diameter. Each turbine has a separate penstock.

The generating equipment consists of two 6000 HP and two 3750 HP main units, together with two 330 HP exciters, all of the horizontal type. The two 6000 HP turbines were built by The Wellman-Seaver-Morgan Company. They operate at 225 RPM and are



6 000 HP TURBINES OF THE CALGARY POWER CO.



6 000 HP TURBINE, WITH TOP OF CYLINDRICAL CASING REMOVED

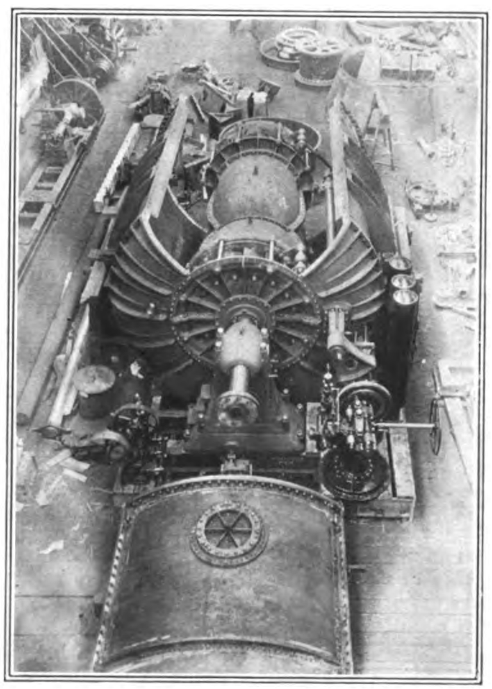
twin central-discharge wheels enclosed in cylindrical plate steel casings with end connection to the penstock. The runners and gates are cast steel. Unit No. 1 was installed in 1910, and was the first turbine built in either this country or Canada, having runners of the mixed-flow type made of cast steel.

The casing of this unit is unique in design. It is so arranged that the entire top may be removed in one piece, permitting the shaft and runners to be lifted out of the bearings and removed without disturbing the generator. A very important objection to the cylinder case wheel is thus eliminated. The shaft of the ordinary cylinder case turbine must be withdrawn through the front head, necessitating removal of the generator and turbine bearings, and dismantling of the gate mechanism.

These turbines are equipped with 60 000 ft. pound, Type N-14, Lombard governors. The governors are connected to a rotating gate shaft which is in turn connected to the gate operating rings by two adjustable rods. There are two operating rings to each set of gates, the gates being connected to the rings at each end by links.

Both bearings are oil lubricated. The front bearing takes the unbalanced thrust of the unit, and is ring-oiling. The rear bearing is enclosed in a water-cooled housing, and is lubricated by a circulation of oil from a small pump driven from the turbine shaft. There is no center bearing between the runners. The shaft is designed to be self-supporting.

The generators are 4000 K. V. A., 3 phase, 60 cycle, 12 000 volt alternators. The voltage is stepped up to 55 000 for transmission to Calgary.



ANOTHER SHOP VIEW OF 6 000 HP TURBINE

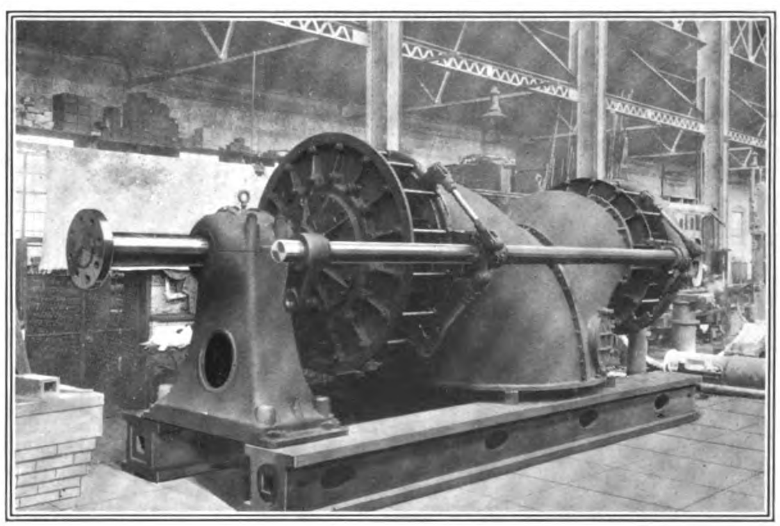
THE CONNECTICUT POWER COMPANY

POWER HOUSE OF THE CONNECTICUT POWER CO.

THE plant of the Connecticut Power Company is located at Great Falls, on the Housatonic River, near Falls Village, Conn. It was built by the Stone & Webster Engineering Corporation of Boston. The initial development is 15 000 HP under 90 ft. head. The ultimate capacity will be 20 000 HP.

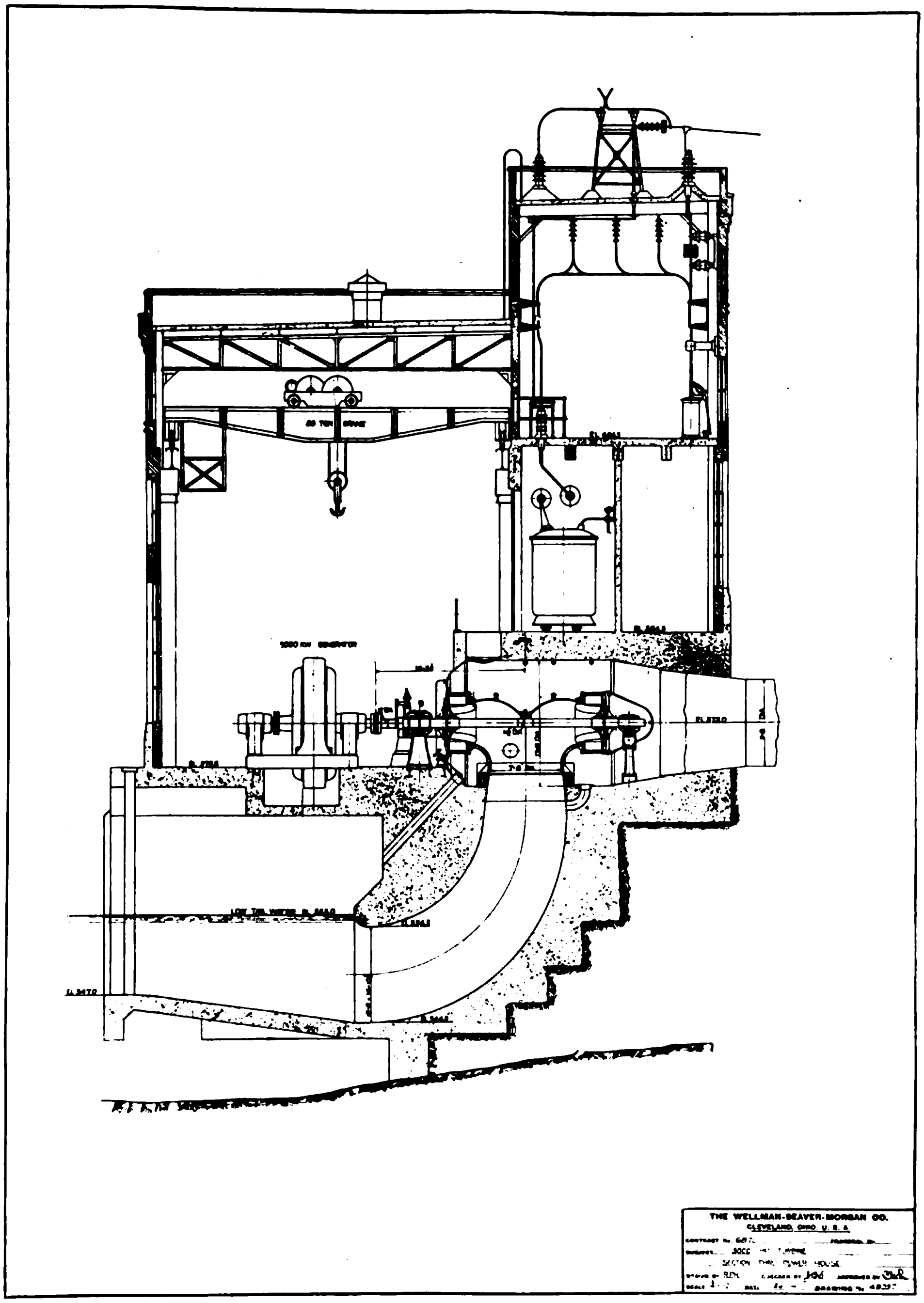
A concrete gravity dam was constructed just above Great Falls, diverting water into a concrete-lined canal about 1900 ft. long leading to a forebay adjacent to the power house. Three 9 ft. diameter penstocks convey the water to the present installation of three main turbine units. Provision is made for the future installation of a fourth main unit. There are two exciters, each supplied by a separate 3 ft. diameter penstock.

The generating equipment consists of three 5000 HP turbines direct-connected to 3000 KW generators running at 300 RPM. The exciters are 150 HP running at 500 RPM.

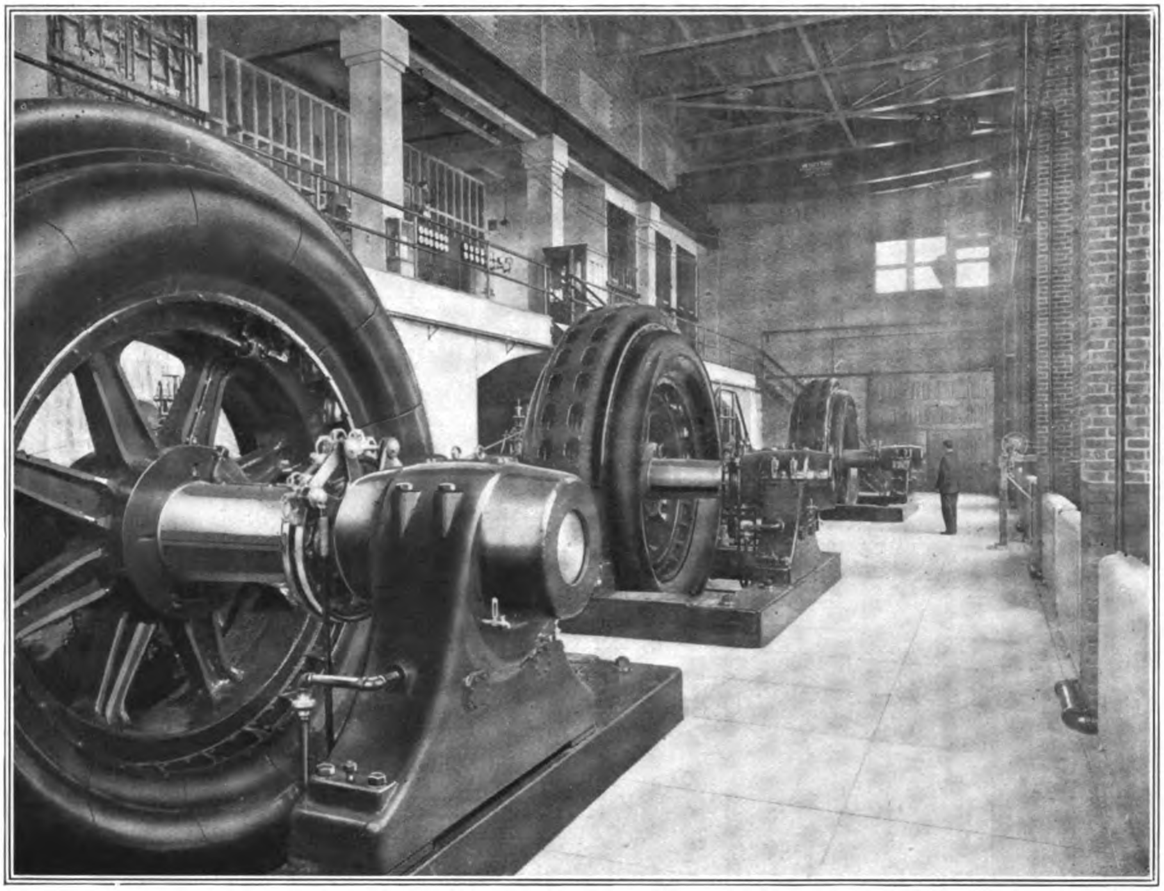


5 000 HP TURBINE, BUILT FOR THE CONNECTICUT POWER CO.

All of the turbines were built by The Wellman-Seaver-Morgan Company. The main units are horizontal central-discharge cylindrical-casing turbines with end connection to the penstock. The runners are cast steel in one piece. Both of the main shaft bearings are ring-oiling self-aligning and are accessible for inspection and adjustment. No center



SECTIONAL ELEVATION OF POWER HOUSE OF THE CONNECTICUT POWER CO.

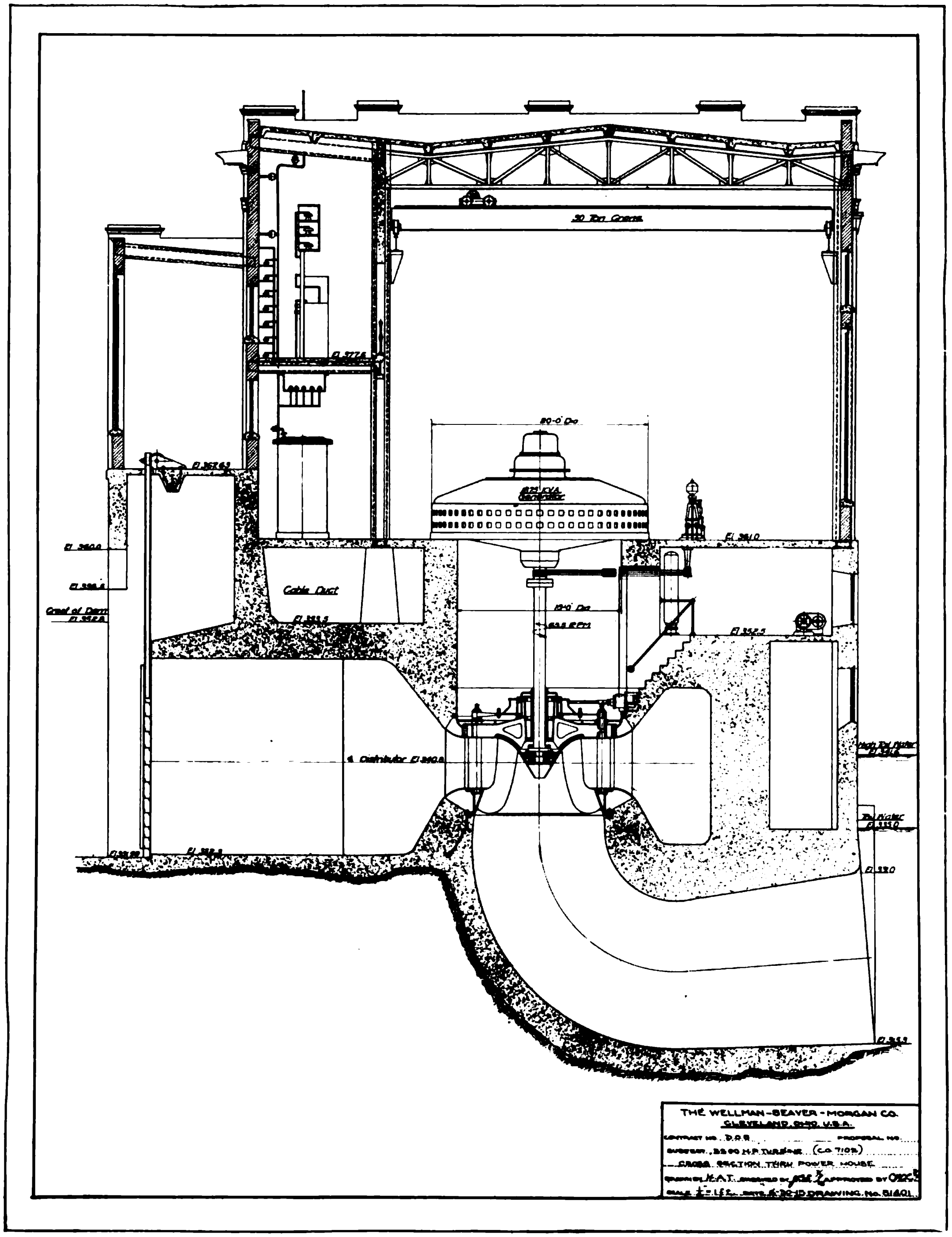


INTERIOR OF POWER HOUSE—CONNECTICUT POWER COMPANY

bearing is provided for the main shaft. It is proportioned to be self-supporting without unduly stressing the material. The main shaft bearing at the generator end is water-cooled and takes the unbalanced lateral thrust of the unit against collars forged on the shaft. The rear main shaft bearing is enclosed in a cone-shaped chamber accessible through an inspection tube.

The gates are cast steel, of the balanced wicket type, connected by links to cast steel operating rings which are in turn connected to a rotating gate shaft. All bearings and pin connections of the gate mechanism subject to wear and action of the water are bronze bushed.

The speed is regulated by 45 000 ft. pound direct-connected Lombard governors. These governors have switch-board speed control and mechanical hand control.



SECTIONAL ELEVATION OF POWER HOUSE

THE OSWEGO FALLS PULP & PAPER CO.

THE Oswego Falls Pulp & Paper Company have owned the water power rights on the east end of the upper dam of the Oswego River in the City of Fulton, N. Y. since 1886. They have operated since that time a waterpower plant of about 3000 HP in connection with a pulp mill, the water wheels being direct-connected to the pulp grinders.

The State of New York started the construction of the barge canal system in 1908, the locks for which are adjacent to the old power plant. This interfered somewhat with the operation of the plant, and when the dam was raised 5 ft. for the barge canal the Oswego Falls Pulp & Paper Company determined to take advantage of the increased power possibilities and erect a modern plant on the site of the old plant. The new plant built in 1915 furnishes power for the motor driven grinders in the new pulp mill, and for the paper mill which was remodeled throughout by replacing the steam-driven machines with individual motor drives. The steam plant is held in reserve, to supplement the new waterpower plant during the dry season. The surplus power is sold to the local power company.

The new waterpower plant consists of three 2200 HP single-runner vertical turbines direct-connected to 1,875 KVA General Electric generators. These turbines were designed and built by The Wellman-Seaver-Morgan Company. The spring type thrust bearings and direct-connected exciters are supported on top of the generator frames. The turbines operate at 65.5 RPM under a head of 17 ft. to 18 ft. Each turbine is controlled by a 30 000 ft. pd. Lombard actuator type governor supplied with oil-pressure by a central pumping system located in the passageway below the generator floor.

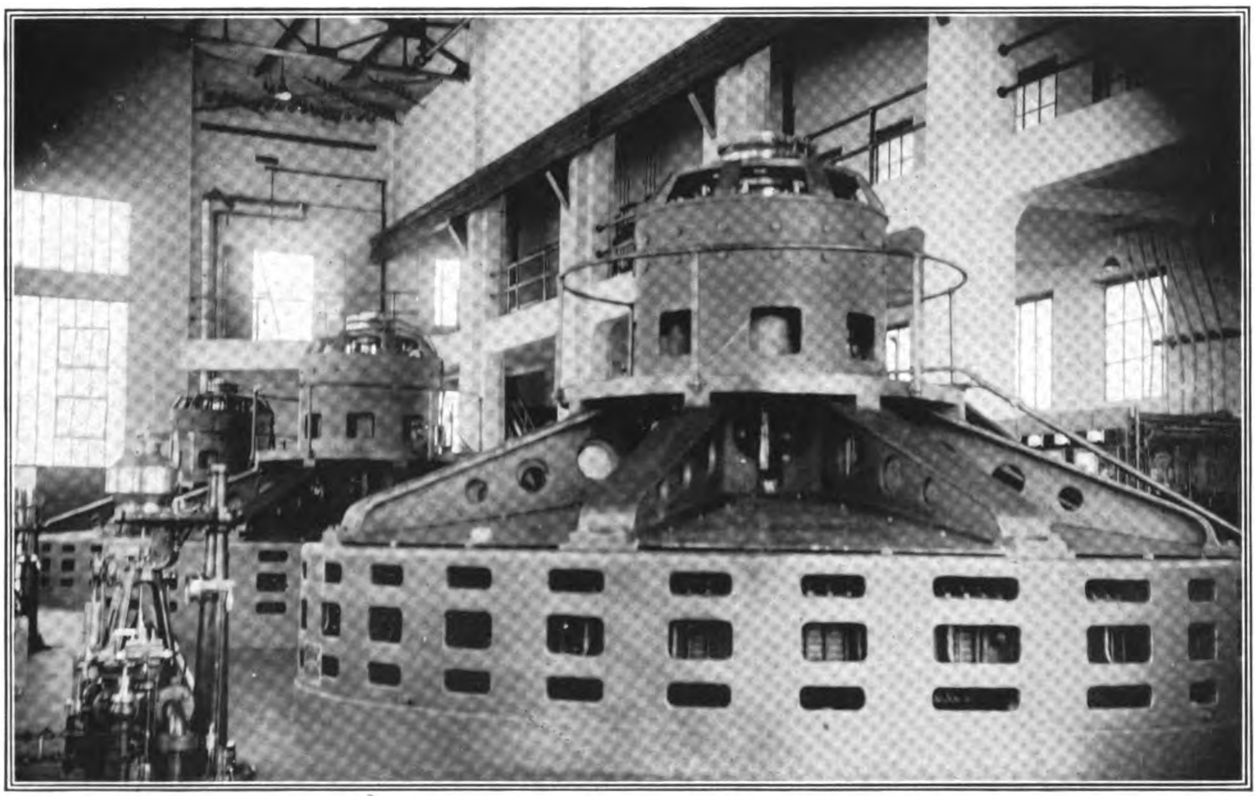
Special mention is made of this plant, not because of its size or unusual characteristics, but because it is typical of a great many comparatively small low head plants which will eventually be built in all parts of this country. Every provision was made in the design of the turbines, wheel chambers, intakes and draft tubes to obtain the highest possible efficiency without unnecessary expense. The cost of maintenance and repairs since this plant was put in operation has been practically negligible. This is a very good example of the superiority of vertical installations compared to horizontal.

The turbine runners are of iron, cast in one piece, and are bolted to a forged flange on the main shaft to facilitate convenient removal. The wicket gates are cast steel. They are operated in balance by two servo-motors or regulating cylinders direct-connected to the operating ring. All details of the gate mechanism are heavy and designed to stand rough usage. All bearings and pin connections are provided with adequate means of lubrication. The links are adjustable for close setting of the wicket gates.

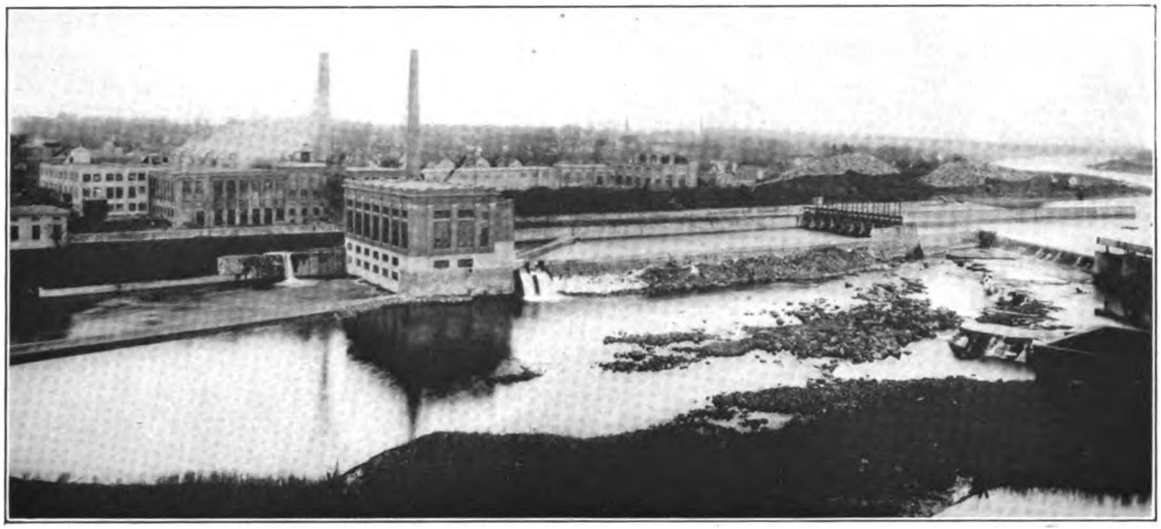
The main shaft bearing is of the lignum-vitae type. It is provided with a circulation of filtered water.

The governors are equipped with switch-board speed control and hydraulic hand control. They operate with oil pressure at 200 lbs. per sq. in. supplied by a central system consisting of two rotary pumps, each having sufficient capacity for the entire plant. Only one pump is in operation at a time, the other being held in reserve. Each pump has an automatic unloading device to prevent excessive pressure in the system independent of the varying requirements of the governors.

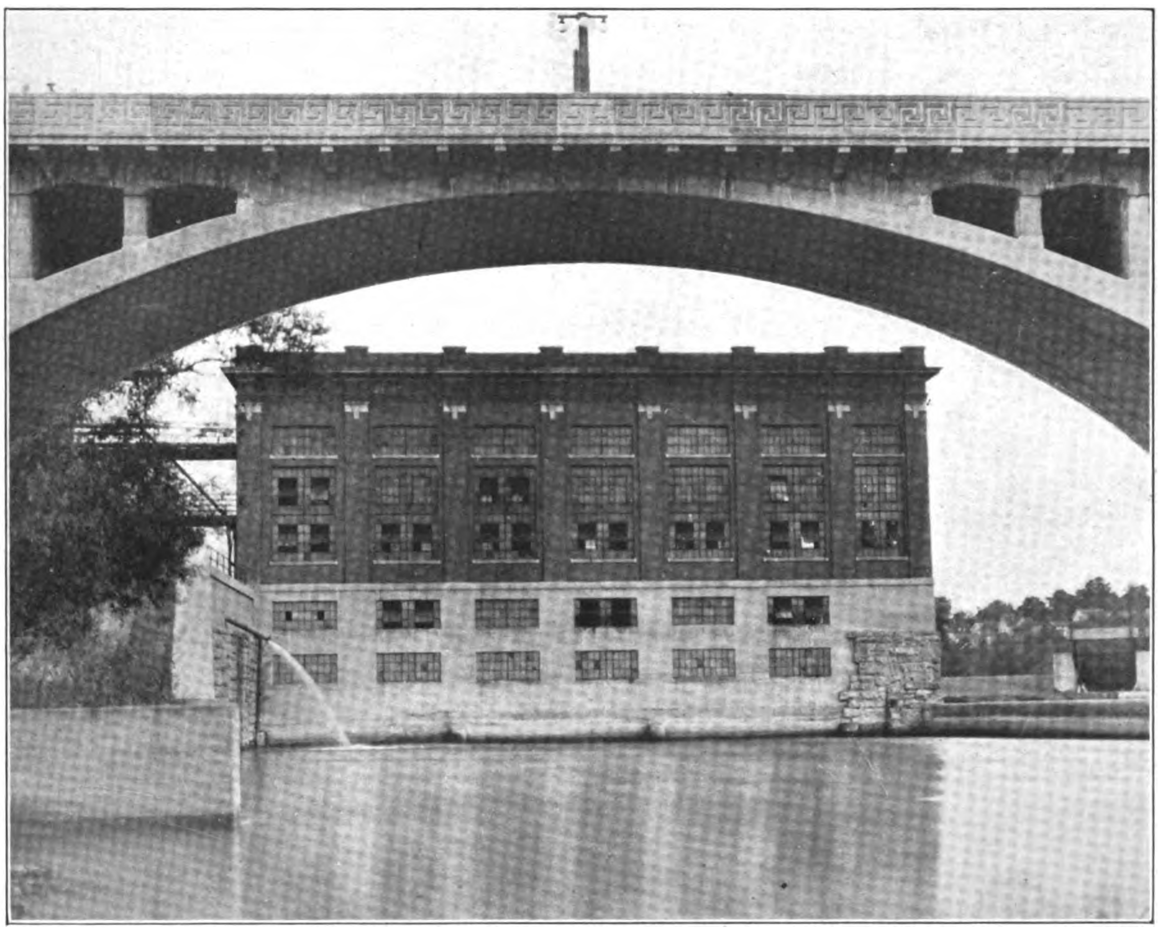
The pumps draw their supply of oil from a central sump tank to which the discharge from the governors is directly connected. Each unit has an individual pressure tank located near the actuator, thus avoiding the inertia effect of the oil in the piping. Each governor has a hand pump which may be used to operate the turbine gates in case the central system pressure should fail.



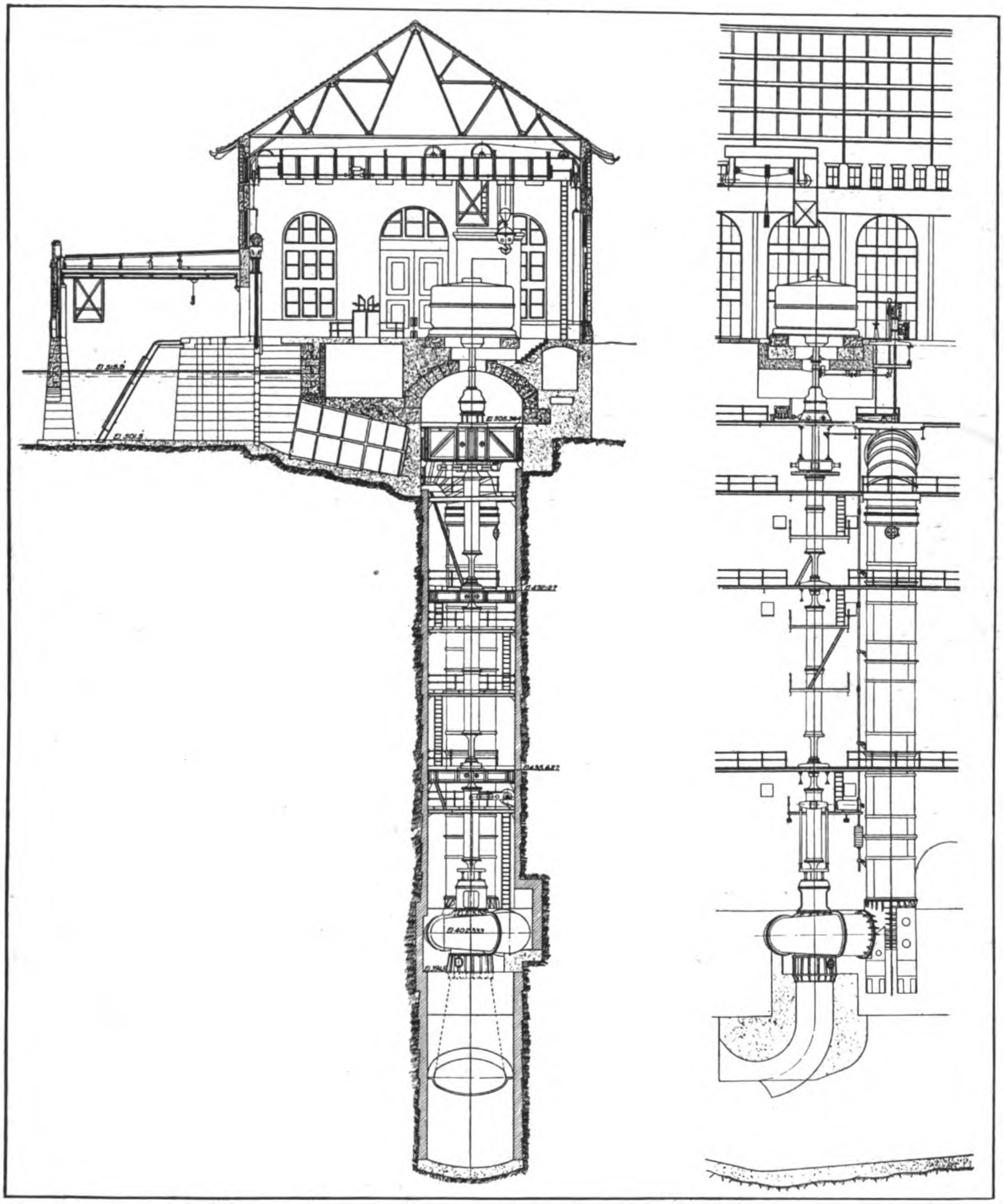
INTERIOR VIEW OF POWER HOUSE, OSWEGO FALLS PULP AND PAPER CO., FULTON, NEW YORK



OSWEGO FALLS PULP & PAPER CO.'S PLANT. HYDRO-ELECTRIC STATION IN FOREGROUND

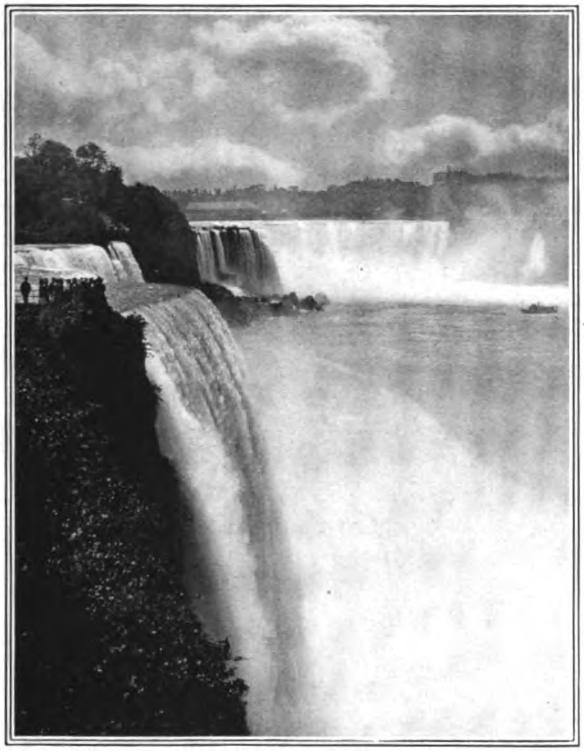


OSWEGO FALLS PULP & PAPER CO. EXTERIOR VIEW OF POWER HOUSE FROM TAILRACE



SECTIONAL ELEVATIONS OF CANADIAN NIAGARA POWER CO.'S PLANT

CANADIAN NIAGARA POWER COMPANY

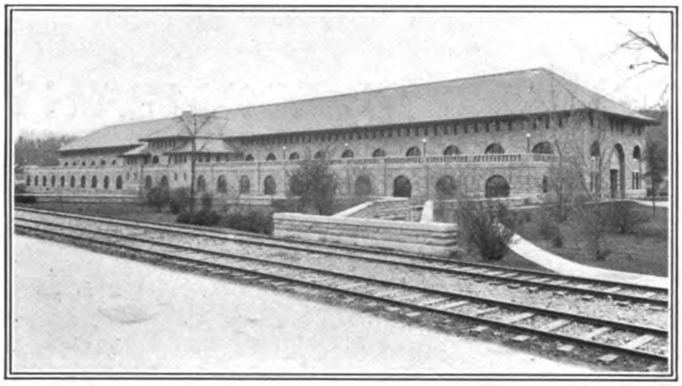


NIAGARA FALLS SHOWING PLANT
OF THE CANADIAN NIAGARA POWER CO.

THE Canadian Niagara Power Company is an allied interest of the Niagara Falls Power Company, which made the first large hydro-electric development at Niagara Falls. Plant No. 1 of the Niagara Falls Power Company, on the American side of the river, was put in operation in 1895 with an initial output of 15 000 HP. This plant now contains ten 5500 HP turbines and plant No. 2, built subsequently, contains eleven 5500 HP turbines. The Niagara Falls Power Company has recently been consolidated with the Hydraulic Power Company which has 13 units of 10 000 HP and 3 units of 37 500 HP. The plant of the Canadian Niagara Power Company above Horseshoe Falls, on the Canadian side of the river, contains five 10 000 HP and five 12 500 HP units. The last three 12 500 HP units were constructed by The Wellman-Seaver-Morgan Company. The total capacity of the four plants is now about 475 000 HP.

The 12 500 HP turbines built for the Canadian Niagara Power Company, are of the vertical single-runner spiral-casing type operating at 250 RPM under 140 ft. head. The turbines are placed at the bottom of a pit about 120 ft. below the generator floor and connected to the generator by a long vertical shaft composed of alternate sections of forged nickel steel and welded steel tubing. Each forged section has a guide bearing mounted on a bridge between the walls of the pit. The thrust bearings are located just below the generators. They are of the combined oil-pressure and roller type, and carry the total weight of the rotating parts of the generator and turbine together with the inter-connecting shaft.

The water is drawn from the river through a forebay canal about 200 ft. long, to the head gates at the power house, and from thence conveyed to the turbines by means of vertical riveted steel penstocks. The draft tubes of the turbines empty into a tail race tunnel excavated in the rock, which discharges into the lower river behind the Horseshoe Falls. The tail race tunnel has sufficient slope to discharge the total quantity of water used by the plant without running full.



POWER HOUSE OF THE CANADIAN NIAGARA POWER CO.

The tail race or discharge tunnel is 25 ft. high, with a maximum width of about 19 ft., the cross section being of horseshoe form. This tunnel is about 2200 ft. long, and has a gradient of 7 ft. per thousand feet of length to a point about 100 ft. from the portal. From that point to the portal the drop is about 11 ft. The walls and floor of the tunnel are lined with concrete faced with vitrified brick, as a protection against the danger of erosion due to the high velocity of the water.

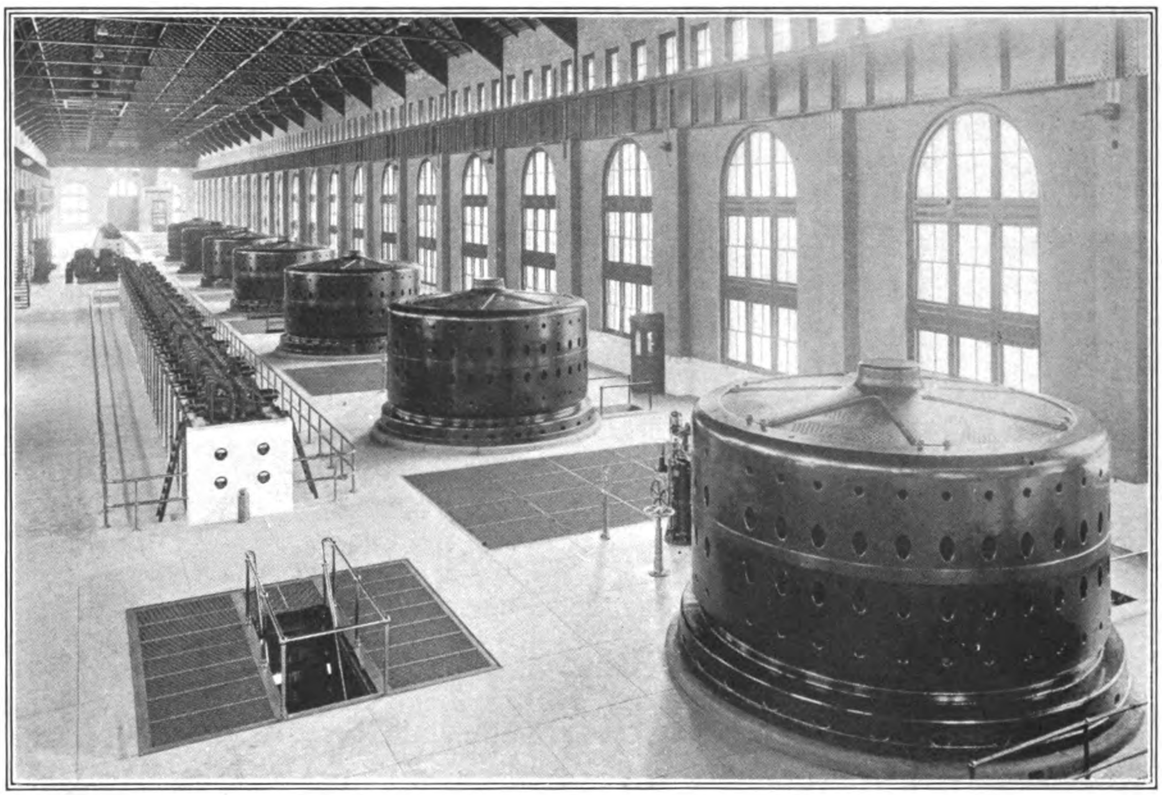
The wheel pit is an excavation about 160 ft. deep and 18 ft. wide, extending the full length of the power house. It is in solid rock and is lined with brick to prevent seepage. On account of movements which take place in the walls of the pit, all supports for the turbines and shafting are permanently attached to only one wall.

Contrary to the usual modern practice, all of the turbines in this plant are equipped with cylinder gates instead of the customary wicket type. This arrangement is used because the governor connections are simpler and because the leakage is less with cylinder than with wicket gates.

CANADIAN NIAGARA POWER HOUSE SHOWING TORONTO POWER CO.'S PLANT AND INTAKE OF THE ONTARIO POWER CO. IN THE BACKGROUND

The efficiency characteristics of a cylinder gate turbine are relatively poorer than those of a wicket gate turbine, except at full gate. It is possible to design a cylinder gate turbine to have just as high peak efficiency as a wicket gate wheel, but the peak will be at full load. This characteristic is not objectionable in this plant because the load is very steady and the wheels are run practically all of the time at full load.

The generators are 11 000-volt, 3-phase, 60-cycle vertical alternators. The generator voltage is stepped up to 22 000 volts for transmission to Buffalo. This plant is operated in parallel with the other plants of the Niagara Falls Power Company.



CANADIAN NIAGARA POWER CO. PRESENT INSTALLATION CONSISTS OF FIVE 10 000 HP AND FIVE 12 500 HP UNITS